09

CLIMATE CHANGE RESEARCH REPORT CCRR-09

# The Known and Potential Effects of Climate Change on Biodiversity in Ontario's Terrestrial Ecosystems:

## Case Studies and Recommendations for Adaptation

*Responding to Climate Change Through Partnership*

Ontario

## Climate Change and MNR: A Program-Level Strategy and Action Plan

The following describes how the Ministry of Natural Resources works to contribute to the Ontario Government's commitment to reduce the rate of global warming and the impacts associated with climate change. The framework contains strategies and sub-strategies organized according to the need to understand climate change, mitigate the impacts of rapid climate change, and help Ontarians adapt to climate change:

**Theme 1: Understand Climate Change**

***Strategy #1:*** Gather and use knowledge in support of informed decision-making about climate change. Data and information gathering and management programs (e.g., research, inventory, monitoring, and assessment) that advances our knowledge of ecospheric function and related factors and forces such as climate change are critical to informed decision-making. Accordingly, MNR will work to:

- Strategy 1.A: Develop a provincial capability to describe, predict, and assess the important short- (0-5 years), medium- (5-20 years), and long-term (20+ years) impacts of climate change on the province's ecosystems and natural resources.
- Strategy 1.B: Model the carbon cycle.

***Strategy #2:*** Use meaningful spatial and temporal frameworks to manage for climate change. A meaningful spatial and temporal context in which to manage human activity in the ecosphere and address climate change issues requires that MNR continue to define and describe Ontario's ecosystems in-space and time. In addition, MNR will use the administrative and thematic spatial units required to manage climate change issues.

**Theme 2: Mitigate the Impacts of Climate Change**

***Strategy #3:*** Gather information about natural and cultural heritage values and ensure that this knowledge is used as part of the decision-making process established to manage for climate change impacts. MNR will continue to subscribe to a rational philosophy and corresponding suite of societal values that equip natural resource managers to take effective action in combating global warming and to help Ontarians adapt to the impacts of climate change.

***Strategy #4:*** Use partnership to marshal a coordinated response to climate change. A comprehensive climate change program involves all sectors of society as partners and participants in decision-making processes. The Ministry of Natural Resources will work to ensure that its clients and partners are engaged.

***Strategy #5:*** Ensure corporate culture and function work in support of efforts to combat rapid climate change. Institutional culture and function provide a "place" for natural resource managers to develop and/or sponsor proactive and integrated programs. The Ministry of Natural Resources will continue to provide a "home place" for the people engaged in the management of climate change issues.

***Strategy #6:*** Establish on-site management programs designed to plan ecologically, manage carbon sinks, reduce greenhouse gas emissions, and develop tools and techniques that help mitigate the impacts of rapid climate change. On-site land use planning and management techniques must be designed to protect the ecological and social pieces, patterns, and processes. Accordingly, MNR will work to:

- Strategy 6.A: Plan ecologically.
- Strategy 6.B: Manage carbon sinks.
- Strategy 6.C: Reduce emissions.
- Strategy 6.D: Develop tools and techniques to mitigate the impacts of rapid climate change.

**Theme 3: Help Ontarians Adapt**

***Strategy #7:*** Think and plan strategically to prepare for natural disasters and develop and implement adaptation strategies. MNR will sponsor strategic thinking and planning to identify, establish, and modify short- and long-term direction on a regular basis. Accordingly, MNR will work to:

- Strategy 7.A: Sponsor strategic management of climate change issues.
- Strategy 7.B: Maintain and enhance an emergency response capability.
- Strategy 7.C: Develop and implement adaptation strategies for water management and wetlands.
- Strategy 7.D: Develop and implement adaptation strategies for human health.
- Strategy 7.E: Develop and implement adaptation strategies for ecosystem health, including biodiversity.
- Strategy 7.F: Develop and implement adaptation strategies for parks and protected areas for natural resource-related recreational opportunities and activities that are pursued outside of parks and protected areas.
- Strategy 7.G: Develop and implement adaptation strategies for forested ecosystems.

***Strategy #8:*** Ensure policy and legislation respond to climate change challenges. Policy, legislation, and regulation guide development and use of the programs needed to combat climate change. MNR will work to ensure that its policies are proactive, balanced and realistic, and responsive to changing societal values and environmental conditions.

***Strategy #9:*** Communicate. Ontarians must understand global warming, climate change, and the known and potential impacts in order to effectively and consistently participate in management programs and decision-making processes. Knowledge dissemination through life-long learning opportunities that are accessible and current is critical to this requirement. MNR will raise public understanding and awareness of climate change through education, extension, and training programs.

2008-01261/

# The Known and Potential Effects of Climate Change on Biodiversity in Ontario's Terrestrial Ecosystems: Case Studies and Recommendations for Adaptation

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September 2007

Ontario

Applied Research and Development Branch • Ontario Ministry of Natural Resources

**Library and Archives Canada Cataloguing in Publication Data**

Varrin, Regina
The known and potential effects of climate change on biodiversity in Ontario's terrestrial ecosystems : case studies and recommendations for adaptation

(Climate change research report ; CCRR-09)
Includes bibliographical references.
Available also on the Internet.
ISBN 978-1-4249-4947-2

1. Biodiversity—Climatic factors—Ontario. 2. Animal populations—Climatic factors—Ontario. 3. Vertebrates—Monitoring—Ontario. 4. Ecosystem management—Ontario. 5. Biotic communities—Ontario. I. Bowman, Jeffrey C. (Jeffrey Courtland), 1969- . II. Gray, Paul A. III. Ontario. Ministry of Natural Resources. Applied Research and Development. IV. Series.

QH77 C2 V37 2007 333.9509713 C2007-964024-9

© 2007, Queen's Printer for Ontario
Printed in Ontario, Canada

Single copies of this publication
are available from:

Applied Research and Development
Ontario Forest Research Institute
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1235 Queen Street East
Sault Ste. Marie, ON
Canada P6A 2E5

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# Summary

Global climate change has the potential to dramatically alter Ontario's terrestrial ecosystems. We have identified three general classes of mechanisms that can affect species as a result of climate change: demographic, phenological, and genetic. Each of these classes can cause population expansions or contractions depending on the ecology of particular species. To demonstrate the range of potential climate effects, we present case studies for deer tick (*Ixodes scapularis*), moose (*Alces alces*), Eastern Bluebird (*Sialia sialis*), polar bear (*Ursus maritimus*), red squirrel (*Tamiasciurus hudsonicus*), and Black-capped Chickadee (*Poecile atricapillus*). These case studies show that although responses to climate change are likely to be species-specific, some responses can be generalized based on species characteristics such as geographic range size and location within Ontario, movement ability, and genetic variability. We also summarize a review of climate change studies of vertebrate species that occur in Ontario. Of 175 species studied, 10 species demonstrate evidence of population contraction, 62 demonstrate population expansion, and 103 demonstrate equivocal responses. This review forms a basis not only for future studies but also for assessing species of conservation concern.

Effects of climate change on communities and ecosystems are difficult to generalize because of complexities associated with biotic interactions. Climate change may affect different species in communities disproportionately (asymmetry). It may also reduce synchrony between species. Or it can act synergistically with other processes such as habitat fragmentation to create emergent effects. Finally, responses by species and systems to climate change can be non-linear, making changes rapid and prediction difficult. We discuss characteristics of these interactions in the context of climate change to make generalizations and to identify gaps in knowledge. We also make recommendations for management, research, and adaptation strategies.

# Résumé


## Les effets connus et probables du changement climatique sur la biodiversité des écosystèmes terrestres en Ontario : études de cas et recommandations d'adaptation

Le changement du climat mondial pourrait bouleverser l'équilibre des écosystèmes terrestres de l'Ontario. Nous avons cerné trois grandes catégories de mécanismes qui peuvent nuire aux espèces à cause du changement climatique : démographique, phénologique, et génétique. Chacune de ces catégories peut provoquer une expansion ou une contraction de la population selon l'écologie des espèces particulières. Pour apporter la preuve des nombreux effets climatiques probables, nous proposons des études de cas sur la tique (*Ixodes scapularis*), l'orignal (*Alces alces*), le merle-bleu de l'Est (*Sialia sialis*), l'ours polaire (*Ursus maritimus*), l'écureuil roux (*Tamiasciurus hudsonicus*), et sur la mésange à tête noire (*Poecile atricapillus*). Ces études de cas illustrent que, s'il est vrai que les mesures prises en réponse au changement climatique sont susceptibles d'être propres à des espèces, certaines de ces mesures peuvent être généralisées en fonction des caractéristiques d'une espèce comme la taille de l'aire géographique et l'emplacement géographique en Ontario, la capacité de déplacement, et la variabilité génétique. Nous résumons également un examen portant sur des études sur le changement climatique et les espèces vertébrées en Ontario. Sur les 175 espèces étudiées, 103 prouvent l'existence d'une contraction de la population, 62 prouvent celle d'une expansion de la population, et 101 apportent des réponses équivoques. Cet examen sert de fondement non seulement à des études futures, mais aussi à l'évaluation des espèces menacées.

Les effets du changement climatique sur les collectivités et les écosystèmes sont difficiles à généraliser en raison de la complexité des interactions biotiques. Le changement climatique pourrait être néfaste à différentes espèces dans les collectivités, et ce, de manière disproportionnée (asymétrie). Cela pourrait aussi réduire la synchronie entre les espèces, ou encore agir de façon synergétique avec d'autres processus comme la fragmentation de l'habitat et créer des effets émergents. Enfin, les réactions des espèces et des systèmes face au changement climatique peuvent être non linéaires, provoquant ainsi des changements rapides et rendant toute prévision difficile. Nous traitons des particularités de ces interactions dans le contexte du changement climatique afin de formuler des généralisations et de cerner l'écart des savoirs. Nous formulons également des recommandations relatives aux stratégies de gestion, de recherche et d'adaptation.


# Acknowledgements


Funding for this project was provided by OMNR's Climate Change Program, under the auspices of Climate Change Project CC-06-07-003, and by Wildlife Research and Development Section.

We are grateful to the following individuals who reviewed all or part of this document: Mark Ball (Trent University), Mark Browning (OMNR), Lisa Buse (OMNR), Colin Garroway (Trent University), Andrew Jobes (OMNR), Adam McAllister (OMNR), Martyn Obbard (OMNR), Chris Risley (OMNR), Art Rodgers (OMNR), and Sue Tully (OMNR). Thanks also to Laura Bjorgan who assisted us in the initial stages of the project. We thank Lisa Buse and Trudy Vaittinen for production support.

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# Introduction

Through many decades of social, cultural, and economic development people have assumed that Earth's climate will behave in the future as it has in the past. Before 1960, the summer and winter seasons in northern Ontario came and went at about the same time every year. The winters were long and cold and the summers were short and warm. Scientists had confidence in estimates of the frequency and intensity of extreme events (e.g., the 100 year high water mark) and towns and cities were designed accordingly. While the climate has always changed, these changes were usually relatively slow. But Earth's climate is different now. Since 1900, the Earth's surface has warmed 0.74±0.18°C, primarily due to human activities post World War II (IPCC 2007). Given that Earth's temperature will continue to increase throughout the 21st Century (Flannery 2005, IPCC 2007), Ontarians need to account for climate change and its uncertainty.

Climate change will significantly affect species (including humans), ecosystems, and most aspects of our society, including human health, the infrastructure we depend on for transportation, employment, clean water, energy production and distribution, agriculture, and forestry (IPCC 2001a, b). Climate change also affects the way agencies such as the Ministry of Natural Resources (MNR) care for the province's natural assets. In response, MNR works with clients and partners to understand climate change, reduce its negative effects on natural systems, and help Ontarians adapt to the changes. Under the climate change strategic plan (see inside front cover of this report), MNR also evaluates its progress to report on the state of knowledge, to identify knowledge gaps, and to determine threats and opportunities for multi-year planning initiatives. This report is 1 of 10 prepared in support of MNR's strategic assessment of its climate change program.

## Causes of Climate Change

Climate is primarily fuelled by energy (heat) from the Sun, and created by dynamic and complex interactions between the atmosphere, hydrosphere (oceans and lakes), cryosphere (ice), land, and organisms. Climate is "average weather", described statistically in terms of the mean and variability of temperature, precipitation, and wind (IPCC 2001a).

As the Sun's rays (short-wave radiation) enter the atmosphere, about 30% of the radiated energy is reflected back into outer space by clouds, dust particles, snow, and ice, 20% is absorbed by clouds, and 50% is absorbed by things on the Earth's surface such as rocks, soil, water, plants, buildings, and pavement. Some of the heat that warms the Earth's surface returns to the atmosphere as long-wave radiation where it is caught by atmospheric gases that are chemically and structurally able to retain this long-wave heat energy. These are greenhouse gases such as carbon dioxide ($CO_2$) and methane ($CH_4$), which stay aloft anywhere from a few years (e.g., $CH_4$ remains in the atmosphere for 21 years) to thousands of years (e.g., sulphur hexafluoride [$SF_6$] remains for up to 3,200 years). The more heat-collecting gas molecules that are in the atmosphere, the warmer it gets.

Historically, greenhouse gases have comprised a small but critical part of the atmosphere. For example, water vapour, $CO_2$, and other naturally occurring greenhouse gases help regulate Earth's climate by capturing heat energy and acting like an insulating blanket. This keeps Earth's surface temperature 33°C warmer than it would otherwise be and provides enough heat for life on Earth.

Climate change is caused by natural events and human activities. For example, solar radiation varies with shifts in Earth's orbit and tilt relative to the Sun, both of which change over tens of thousands of years (Ruddiman 2001). The Sun itself releases varying amounts of energy, affecting global climate (Alverson et al. 2001). Volcanoes cool the atmosphere by spewing fine particles into the upper atmosphere reflecting incoming solar radiation back out into space. In extreme cases, volcanic activity can affect global climate for several years (Robock 2000).

Although humans began altering Earth's ecosystems and emitting increased amounts of greenhouse gases with the invention of agriculture, the industrial revolution that began around 1750 marked the beginning of the release of truly significant amounts of $CO_2$ and $CH_4$ to the atmosphere. More recently, several artificial compounds have been emitted, such as sulfur hexafluoride and perfluoropentane ($C_5F_{12}$). Although emitted in relatively small quantities, these greenhouse gases are potent.

As a result of burning fossil fuels (coal, oil, and gas), converting forests to non-forested conditions (this is deforestation, which contrasts with the sustainable harvest and regeneration of forests), and draining wetlands, atmospheric $CO_2$ has increased 31% since pre-industrial times (IPCC 2001a). The increased concentrations of greenhouse gases keep more heat energy in the lower atmosphere, which increases temperatures and alters precipitation (IPCC 2001b). Because global temperature has increased dramatically since 1978 but the Sun's energy reaching the Earth has remained constant, most scientists have concluded that this rise in temperature is due to greenhouse gas emissions from human activity (National Academies of Science 2006).

# Ontario's Climate

## Ontario's Climate Change in the Last Hundred Years

Although the average annual global temperature warmed about 0.74°C during the past century (IPCC 2007), the warming trend in Canada was double the world average. However, the warming was not uniform across the country. For example, average annual temperature increased about 2.0°C in northwestern British Columbia and the Kluane region of the Yukon Territory, 1.2°C in southcentral Canada, and was unchanged in Atlantic Canada over the same period (Environment Canada 2006).

People living in southern Ontario have consistently experienced warmer than normal temperatures for many years. For example, the annual average temperature near Sandbanks Provincial Park, south of Belleville on the shores of Lake Ontario, increased 1.14°C between 1921 and 2004 (Lemieux et al. 2007). In northwestern Ontario, near Wabakimi Provincial Park, east of Sioux Lookout, the average annual temperature increased 1.19°C between 1930 and 2004, and average annual precipitation increased 32.4 mm. Similarly, the average annual temperature near Quetico Provincial Park along the Canada-U.S. border increased 1.06°C between 1895 and 2004, and average annual precipitation increased 231.1 mm between 1895 and 1992 (Lemieux et al. 2007). Warming in northeastern Ontario was significant as well. Between 1938 and 2004, the average annual temperature near Lady Evelyn-Smoothwater Provincial Park north of Sudbury increased 1.14°C and total annual precipitation increased 24.7 mm between 1939 and 2004. Along the James Bay coastline, the average annual temperature at Tidewater Provincial Park increased 1.24°C between 1895 and 2004 (Lemieux et al. 2007).

Other important climatic changes occurred during the 20th Century as well. For example, winter snow cover in the Northern Hemisphere has decreased about 60% since the late 1960s (IPCC 2001b). The annual duration of lake and river ice cover in the mid- and high latitudes of the Northern Hemisphere has been reduced by about two weeks. For example, freeze-up occurs about 13 days later and break-up about 4 days earlier than 140 years ago on Lake Simcoe, just north of Toronto (CCME 2003). In addition to increased annual precipitation of 0.5 to 1.0% in the mid- to high latitudes of the Northern Hemisphere, heavy precipitation events have increased 2 to 4% over the same period.

## Ontario's Climate Change in the Next Hundred Years

Effective responses to global warming require indications of how Ontario's climate might change during the 21st Century. Whereas it is widely recognized that greenhouse gas emissions must be stabilized to mitigate the effects of global warming and initiatives such as the Kyoto Protocol can lead to emission reductions, future levels of greenhouse gases are not clearly understood.

The Earth's surface is projected to warm by 1.1 to 6.4°C over the next 100 years, with land areas warming more than the oceans, and with the high latitudes (e.g., Ontario) warming more than the lower latitudes (e.g., tropics) (IPCC 2007). The additional heat energy in the atmosphere will increase variability in temperature, precipitation (rain, snow, and ice), and wind. For example, as more heat is trapped in the lower atmosphere by additional greenhouse gases, it is likely that the frequency and size of extreme events such as ice storms, heavy rains, droughts, and wind storms will increase.

Ultimately, 21st Century greenhouse gas emissions will depend on how people around the world behave. For example, if countries choose to increase fossil-fuel-based industrial output, emissions will grow more than if countries choose to conserve energy by using renewable energy whenever possible. Given the uncertainty in the amount of emissions and associated effects, natural resource management agencies around the world are using a number of climate models and scenarios of human behaviour to depict a range of potential climatic conditions and impacts that may appear in the next 100 years. Virtually all aspects of weather, including precipitation, winds, air pressure, and humidity will be affected by increased greenhouse gas emissions. Each global climate scenario is unique, producing somewhat different projections of future climate.

Forty scenarios of human behaviour have been approved by the Intergovernmental Panel on Climate Change for use in modelling potential effects. Each scenario has a different set of assumptions about future social and economic conditions (Colombo et al. 2007). A scenario is a possible outcome, not a prediction, because the amount of greenhouse gas emissions in the future depends on highly variable factors such as global population, human behaviour, technological development, and the carbon sink/source behaviour of land and water ecosystems. The climate scenarios are based on the work of thousands of scientists and modellers who have:

1. Developed greenhouse gas emission statements based on a range of human behaviour scenarios from a conserver-oriented approach to a heavily industrialized approach to life on Earth.
2. Correlated the greenhouse gas emissions to temperature and integrated them into global climate models. Many models have been developed and tested in the last 20 years and continue to be refined. These models use mathematical equations to represent Earth's atmosphere and permit the user to generate climatic conditions based on projected changes to Earth's atmospheric chemistry in relation to land surface, vegetation, oceans, and sea ice (Fig 1).

Climatologists have predicted the potential change in Canada's climate (Fig. 2). For example, 32 General Circulation Model (GCM) and scenario experiments compiled by the Pacific Climate Impacts Consortium (PCIC 2006) project annual mean temperature increases of 3.1 to 10.6°C by the 2080s over Canada's terrestrial ecosystems, which is about double the projected global average temperature change (PCIC 2006). The 32 GCM experiments suggest mean annual precipitation changes ranging from -0.2 to +8.7% for the 2020s, +0.3 to 16.7% for the 2050s, and +2.5 to 19.2% for the 2080s. It is important to note that these changes will not be uniform across the country.

For example, the A2 scenario, a mid-range scenario, anticipates greenhouse gas levels (Nakicenovic 2000) reaching 1,320 parts per million by volume (ppmv) in $CO_2$ equivalents by 2100 (a $CO_2$ equivalent expresses the energy-trapping properties and length of time it remains in the atmosphere in terms of the amount of $CO_2$ producing the same warming effect of any greenhouse gas). In an A2 world, Earth's human population reaches 15 billion by 2100 and people rely more on fossil fuels than the more conserver-oriented scenarios. In an A2 world, Ontarians will be subjected to significant warming, with the greatest increases (6 to 7°C) projected for people living in the north near Hudson Bay (Fig. 3). The average annual temperature of southwestern Ontario, including Toronto and the Niagara Peninsula, will increase 5 to 6°C. Across the province, warming will be greater in winter than summer and in the north than the south (Colombo et al. 2007).

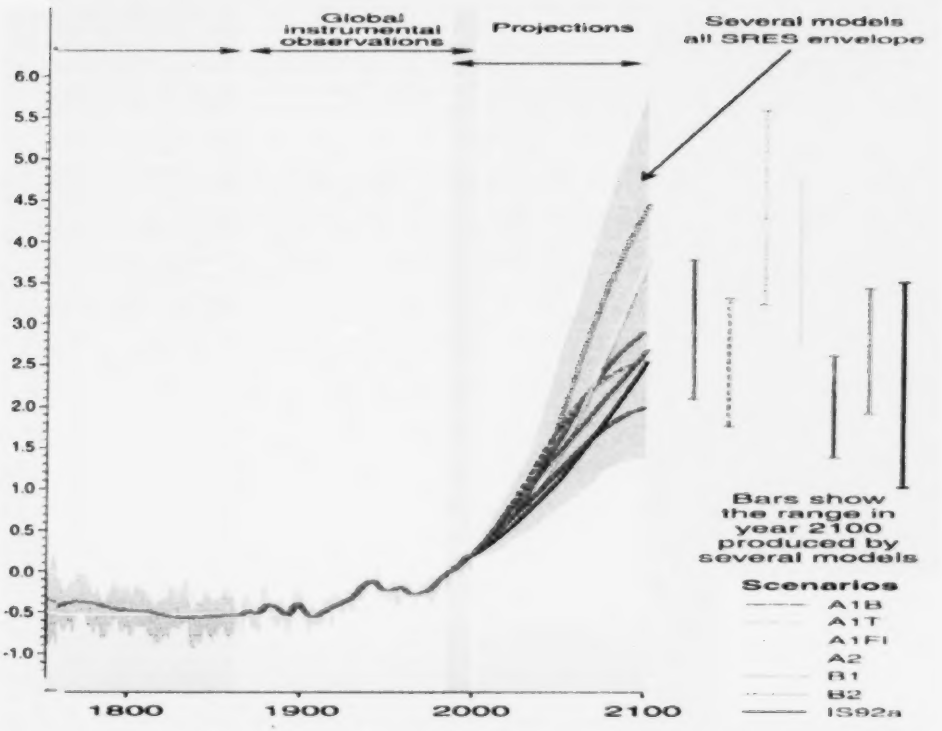


***Fig.1.*** *Global mean temperature change (°C) associated with examples of SRES scenarios describing the impacts of human behaviour through the 21st century (IPCC 2001a).*

## Responding to Climate Change

Climate-driven changes to Ontario's ecosystems in the 21st Century are important and require management agencies such as MNR to respond with new approaches. However, these approaches require education and extension programs. Biodiversity will change due to the climate, human activities, the movement of indigenous and non-indigenous species, and natural disturbances such as fire. Many species will acclimate (phenotypic variation) and/or adapt (genotypic variation) to changing conditions; others will not. Species with a high rate of reproduction, ability to move long distances, rapidly colonize new habitats, tolerate humans, and survive within a broad range of bio-physical conditions will be most successful in finding new niches (Gray 2005).

Climate change will greatly affect ecosystem composition, structure, and function. In some areas, novel ecosystems will develop, altering the existing forest, wetland, and grassland ecosystems now found in Ontario. From a socio-economic perspective, a shorter winter and reduced ice cover on lakes will affect skiing, snowmobiling, and ice fishing activities; longer periods of warmer weather may extend opportunities to pursue outdoor activities such as camping, canoeing, and swimming (Lemieux et al. 2007).

Climate change will affect many of the societal and environmental values that Ontarians take for granted. As a result, the timing and extent of climate change need to be better understood, especially in sectors where long-term planning is needed. Knowing when to act, what actions to take, and whether it is wiser to be proactive or reactive depends on understanding the potential benefits and risks to Ontario's infrastructure, human activities, and ecosystems. Key management strategies include:

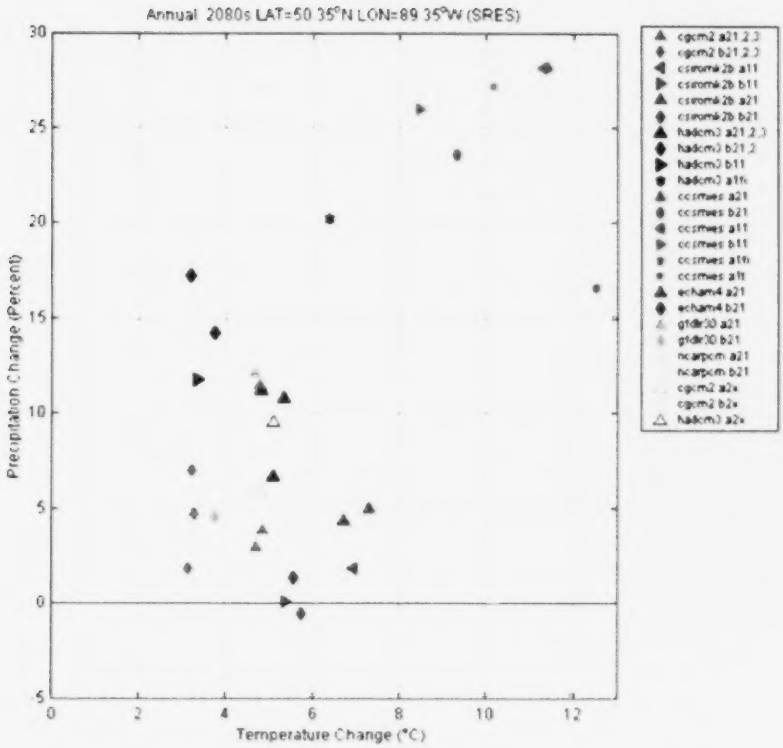


***Fig. 2.*** *A scatterplot depicting the results of 25 climate model-emission scenario experiments for average annual precipitation change (%) and average annual temperature change (°C) for Wabakimi Provincial Park east of Sioux lookout in northwestern Ontario during the 2080s (Lemieux et al. 2007).*

1. Understanding the effects of climate change through science, including research, inventory, monitoring, and assessment.
2. Reducing the negative effects of climate change using strategies that are based on the principles of adaptive management, strategic planning, and on-site management (e.g., wetland protection or remediation).
3. Helping people adapt through economic diversification and education, extension, and training. It is notable that the countries attending the 2005 climate change conference in Montreal to review and discuss future programs under the auspices of the United Nations Framework Convention on Climate Change and the Kyoto Protocol agreed that the development of adaptation tools and techniques should receive significant attention during the next 5 years.

## Species Distribution and Abundance in Response to Climate Change

The distribution and abundance of a species across its geographic range is related to both biotic (e.g., food, competition, and disease) and abiotic (e.g., climate and substrate) factors. There is a relationship between distribution and abundance, such that the greatest species abundances tend to occur in the centre of a species' geographic range (Brown 1995). There remains some debate about the cause of this general pattern, but recent research suggests that it results because the fundamental niche of the species is centred at the core of its range

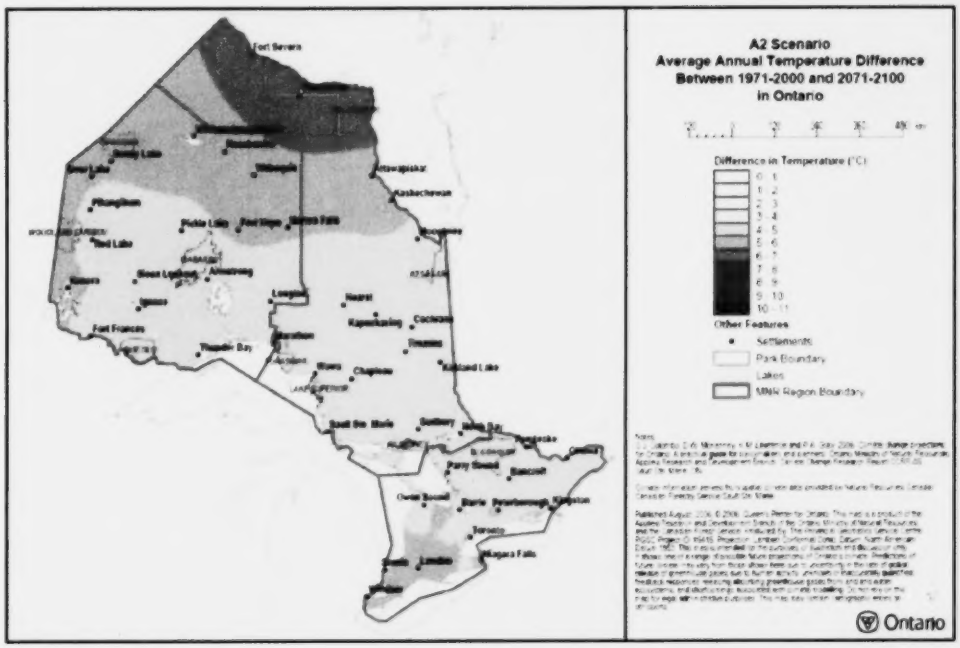


***Fig. 3.*** *Projected change in average annual temperature between 1971 and 2100 using the A2 scenario in the Canadian coupled global climate model (Colombo et al. 2007).*

(and therefore, carrying capacity is higher at the range centre) (Brown 1995). Conceptually, the distribution of this niche is related to factors such as a species' climate envelope, which describe the observed relationship between a species' distribution and climate (Fig. 4) (Luoto et al. 2005). Given that the climate envelope (e.g., temperature and precipitation requirements) is an important part of the fundamental niche, climate change is a significant determinant of a species' distribution and abundance.

Biotic and abiotic factors may limit the range of a species through direct mortality or by affecting such processes as reproductive rate, metabolic rate, and availability of habitat and food (Price and Glick 2002, Parmesan et al. 2005). For example, Gray Jay (*Perisoreus canadensis*) declines following warmer autumns may be caused by the rotting of hoarded food (Waite and Strickland 2006).

The relative importance of climate conditions during different seasons varies with each species. For some predators snow accumulation can be important for successful predation (Post et al. 1999). For other species heat stress in summer is a major cause of mortality. In some cases the minimum or maximum value of a climatic variable is critical. For example, painted turtles (*Chrysemes picta*) may die when exposed to temperatures below -7°C (Packard and Janzen 1996). In other cases averages are sufficient to explain population trends. Opposums (*Didelphis virginianus*) cannot live in areas where the average January temperature drops below -7°C, but they can survive lower temperatures by skipping foraging and resting in their dens for a few days at a time (Brocke 1970).

There are several ways to examine the effects of climate on terrestrial fauna, and to determine how climate change may affect species and their habitat in the future. A common method is to study the effects of large-scale cyclical climatic variation such as the North Atlantic Oscillation (Stenseth et al. 2002). Patterns in the fossil record can also provide clues about range dynamics during ice ages and inter-glacial periods (Parmesan et al. 2005). On a smaller scale, laboratory studies can provide insight into how organisms and communities may respond to enhanced $CO_2$, increased UV radiation, and higher temperatures (Parmesan et al. 2005). Alternatively, analogous

systems such as altitudinal gradients may be used. Finally, models can be used to forecast how species and communities may respond under different scenarios of climate change (Pearson and Dawson 2003). Failure to determine how species interact with their enviroments, and how climate change might affect these interactions, may limit management response, thereby making species more vulnerable to declines or extinctions (Herman and Scott 1992).

A species' range limits are affected by different factors at different boundaries. Northern limits are often determined by abiotic factors such as climatic constraints whereas southern limits tend to be determined by biotic factors such as competition (MacArthur 1972, McCarty 2001). This generalization has important consequences for understanding the effects of climate change. As climate envelopes shift north, species whose northern range boundaries are limited by temperature will be released from these limits and will also shift north. At southern boundaries species encounter increased biotic stress (e.g., parasitism and competition) that will result in range contraction. In this review we focus on the relationship between climate change and species distribution and abundance. We consider the various abiotic and biotic mechanisms that will affect changes in distribution and abundance following rapid warming.

## Demography, Genetics, and Phenology

Expanding, contracting, or shifting ranges in response to changing biotic and abiotic factors proceed through three general classes of mechanisms: demographic, genetic, or phenological. Demographic effects include growth or decline of populations due to predation, disease, competition, and the availability of food and habitat. The genetic composition of a species can be modified through inbreeding, hybridization, or adaptation to new conditions. Phenology describes the timing of life history events such as flowering, nesting, or hibernation, which can be affected by climate. Phenological responses to climate change often occur by affecting demography or genetics. Changes in demography, genetics, or phenology of individual species can influence its interactions within biotic communities and result in further changes in distribution and abundance and ultimately in geographic range (Hughes 2000).

## Past and Present Responses to Climate Change

Historically, species that have persisted through a change in climate have shifted in latitude and elevation to stay within a preferred climate envelope. Plants and animals have dispersed into newly suitable climate or adapted to take advantage of changing climates, and often suffered population declines or extinction at the trailing edge of the range (Davis and Shaw 2001).

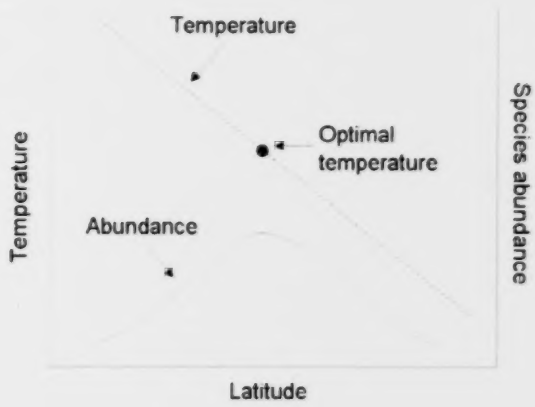


***Fig. 4.*** *Conceptual depiction of the relationship between a species distribution, its abundance, and its optimal climate niche. In the example, temperature is shown as a dashed line. The optimal temperature would be expected to exist at the centre of the species' distribution, creating a hump shape in the species' abundance across its range (solid line). As the latidude decreases from the centre, the temperature increases, and various temperature-related factors would reduce the abundance of the species. Similarly, abundance would be reduced to the north because temperatures are colder than optimal.*

Rising temperatures and changes in precipitation patterns have already affected individual species and communities, especially those at higher latitudes where warming has increased more (McCarty 2001, Parmesan and Yohe 2003, Root et al. 2003). Ranges of mobile species such as flying insects and birds, and habitat generalists such a raccoons (Larivière 2004) have already shifted north (Parmesan and Yohe 2003). The ranges of some Arctic and alpine plants have contracted northwards (Hughes 2000). There is even evidence of genetic changes in some insects, birds, and mammals (Bradshaw and Holzapfel 2006).

## Future Responses to Climate Change

Responses to climate change in the future will be complex. It is likely that some effects will be delayed, impacts will vary according to sex and age, and interactions between species may be influenced (Stenseth et al. 2002). Successful migration of plant species will depend on available soil types, pollinators, and seed dispersal mechanisms (Inkley et al. 2004). Animal dispersal will be limited by availability of migration corridors, suitable habitat, and the movement of forage and prey (Inkley et al. 2004). Temperature and precipitation gradients may not shift in the same direction or at the same rate. Species that require a narrow range of temperature and precipitation conditions (i.e., habitat specialists) will be at greater risk of declines or extinction.

Though the magnitude of temperature change varies depending on the model and scenario used, a northward range shift is projected for many Canadian species, including for example, butterflies and birds (Petersen et al. 2004, Hitch and Leberg 2007). The distribution of many mammals is also expected to shift northwards, resulting in increased competition between those species bounded by Hudson and James Bays in the north, and more southern species expanding their range (Kerr and Packer 1998). Tree species that do not currently occur in Canada will likely migrate into Ontario as the growing season lengthens (Malcolm et al. 2005). The biggest difference between current global warming and previous periods of climate change is the rate at which changes will occur. Trees have historically migrated at less than 1 km per year, but most models predict that trees will need to migrate faster than 3 km per year to keep up with shifting climate envelopes (Malcolm et al. 2002). Therefore, rapid climate change will select for rapidly reproducing and vagile species (i.e., those that can produce large propogule pressure) (Malcolm et al. 2002). Many species generically described as 'weedy' fall into this category, so one outcome of rapid climate change in terrestrial systems may be the selection for traits of weedy species (Malcom et al. 2002).

## Conservation in the Face of a Rapidly Changing Climate

Species are not equally vulnerable to climate change because vulnerability depends on factors such as geographic range size, the size and distribution of populations, the ability to use a variety of habitats, and the ability to disperse into new areas as current habitat changes (Herman and Scott 1992, Torti and Dunn 2005, Schwartz et al. 2006). Species with narrow habitat requirements at multiple life stages may be exposed to cumulative impacts. For example, amphibians lay eggs in standing water, so snow melt and spring precipitation will have a bearing on the survival of eggs and juveniles (Carey and Alexander 2003). Some populations of a species may be more vulnerable than others, depending on, for example, location relative to a range boundary (Herman and Scott 1994), or whether important life history events (i.e., reproduction, migration) are cued by stable events such as photoperiod or variable climatic characters such as temperature. Species within a community may lose synchrony with other species they depend on (e.g., for food) if one is cued by temperature and the other by photoperiod (Visser et al. 1998).

Given that climate is not changing at the same rate across the globe, the impacts of climate change will differ by region. For example, although Tree Swallows (*Tachycineta bicolor*) are now breeding as much as 9 days earlier across their range (Dunn and Winkler 1999), no changes have been observed at Long Point, Ontario where average annual temperatures have not changed significantly (Hussell 2003). In general, temperatures are expected to change faster at higher latitudes (Colombo et al. 2007). Regional differences need to be taken into account when planning conservation actions (McCarty 2001).

Habitat loss, overharvest, pollution, and exotic species are some of the human-induced threats currently faced by species at risk (Venter et al. 2006). In some ecosystems, climate change will potentially emerge as an additional force with an array of effects, and has the potential to aggravate many other anthropogenic factors. Species declines and extinctions are expected to increase as a result of climate change (Thomas et al. 2004, Schwartz et al. 2006). It is important to monitor these changes, understand the processes at work, and improve predictions of future changes so that management and policy can be adapted.

# Methods

This report is divided into two sections. In the first one, we examine how climate change may influence a species' demography, phenology, or genetics, and how this can cause a shift in distribution and abundance. Case studies of predicted species distribution and abundance were developed using information from published sources on climatic constraints and models of future climate. This portion of the document is organized into three sections, one for each class of mechanism (i.e., demography, phenology, and genetics). Within each of these sections, we provide two case studies, one each decribing population expansion and contraction expected from climate change. In the the second section we consider how these species-level effects may play out in Ontario's terrestrial communities. In addition, we have included a glossary of technical terms (Appendix 1) used in this document. Finally, we have prepared a table (Appendix 2) that summarizes peer-reviewed studies describing the effects of climate change on terrestrial vertebrates that occur in Ontario.

## Climate Envelope Models

In the following case studies, a similar approach to climate envelope modelling is used. Climate envelope models identify relationships between climate variables and range limits to predict where species might occur under future climate change scenarios (Pearson and Dawson 2003). These models are sometimes criticized because they do not account for biotic interactions, adaptation, and dispersal mechanisms (Pearson and Dawson 2003). They are most useful at large scales since they do not generally account for regional variation in trends (Hampe and Petit 2005). It is also important to remember that other factors may affect a species' future distribution, such as land use changes or soil types (Pearson and Dawson 2003, Parmesan et al. 2005, Schwartz et al. 2006).

Predicted distributions vary depending on the climate model and scenario used (Petersen et al. 2004, Malcolm et al. 2005). Therefore, it is impossible to predict the future with certainty; the results of our case studies should be taken as indicative, rather than predictive, of the magnitude of the effects climate change may have on species.

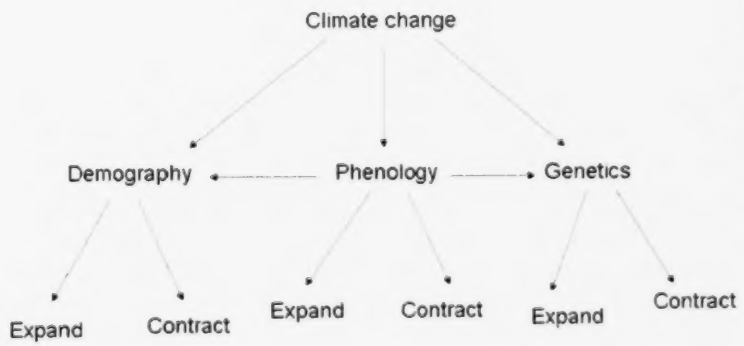


***Fig. 5.*** *A framework for understanding the potential effects of climate change on populations. Classes of effects are demographic, phenological, and genetic. Each of these could cause populations to expand or contract.*

# Demography

The risk of extinction is higher in species with small populations, small ranges, limited ability to disperse, and specialized habitat requirements (Beissinger 2000). Demographic factors such as rates of birth and mortality will therefore be important in declines or extinctions of species induced by climate change. Climate can affect a species' abundance directly, as in the case of the painted turtle, which reaches sexual maturity more quickly in warmer years (Frazer et al. 1993). Snow depth affects the survival of many species, including the fisher (*Martes pennanti*) in Ontario (Carr et al. 2007a). Climate may also act on density-dependent factors such as predation or competition for resources (Stenseth et al. 2002). Arctic fox (*Alopex lagopus*) populations appear to be contracting along the southern edge of their range as red foxes move northwards and outcompete them for resources (Hersteinsson and Macdonald 1992, Selås and Vik 2006).

## Survival

Animals that do not make seasonal migrations must survive harsh weather extremes and variable feeding conditions. In Ontario, the period of extreme weather is most often during winter, as demonstrated by the number of species with their northern range boundaries in the province. Thus, winter temperature appears to be an important limit to the northward expansion of species in Ontario. Winter survival mechanisms include entering hibernation or torpor, seasonal thermogenesis of fat, increasing insulation (by fattening up or growing warmer fur), huddling, or storing food. Whether hibernating or hoarding food for winter, winter survival depends on energy reserves (stored as body fat or hoarded food), length of winter, and the rate at which stores are used (Humphries et al. 2002, Bowman et al. 2005). For example, southern flying squirrels have a flexible northern boundary, as they can expand north during years with good mast production and mild winters, and contract following years with less food or harsher winters (Bowman et al. 2005).

## Reproduction

Climate can affect reproduction by acting on the parents' fitness or the survival or sex ratio of the young. For example, painted turtles have temperature-dependent sex determination (Janzen 1994); their sex is determined by ambient temperatures during embryonic development. As July temperatures increase, the sex ratio becomes skewed towards females. Janzen (1994) predicted that an increase in mean July temperature of 4°C could eliminate male turtles in his Illinois study area.

## Predation

Snow accumulation may influence predation rates in several predator-prey systems, including lynx-hare cycles and wolf-ungulate interactions (Post et al. 1999, Stenseth et al. 2004). Changes in rates of predation on different life stages may counteract one another. For example, salamanders that breed earlier in warmer years have a lower risk of predation due to a decrease in larval development time. However, individuals that develop in warmer habitats are often smaller at maturity and females may not mate as successfully (Root and Schneider 2002).

## Disease and Parasitism

Climate change may affect host-pathogen systems by lowering the host's defenses or by allowing pathogens to expand their range. Changes in temperature or precipitation may increase overwinter survival or rates of transmission of some parasites and diseases (Harvell et al. 2002). Milder winters are predicted to contribute to higher survival of deer and mice, which could result in increased incidence of Lyme disease (National Assessment Synthesis Team 2000). Lyme disease is a bacteria that is spread by the black-legged tick (*Ixodes scapularis*). A northward spread of ticks due to warmer winters could mean northward spread of Lyme disease (Ogden et al. 2006). Parasite and disease range may also expand through increased survival or dispersal of its vectors. For example, insect vectors such as mosquitoes live longer in warmer climates, allowing parasites to complete their

life cycle (Harvell et al. 2002). Pathogens may be more severe in amphibians with immune systems that are already compromised by climate stresses such as increased UV radiation (Harvell et al. 2002).

### Expansion: Deer Tick

The black-legged tick (also called the deer tick) is a common woodland tick that is a vector for Lyme disease, named for the town of Lyme, Connecticut where it was first identified in 1975. Lyme disease is an emerging infectious human disease.

### Ecology of the Deer Tick and Lyme Disease

By feeding on small mammals such as mice, deer ticks can become infected with a bacterium called *Borrelia burgdorferi*, which is the infective agent that causes Lyme disease. When ticks feed on human hosts, the bacterium can be transmitted to humans, causing disease. In addition to Lyme disease, deer ticks can also transmit babesiosis and anaplasmosis to humans (Thompson et al. 2001).

Deer ticks disperse by hitching a ride on hosts, and they have potential for a high rate of spread because they can disperse on the migrating birds (Scott et al. 2001). The ticks' northern range boundary is determined by temperature, and to date, they have been limited to southern Ontario. In cold weather, ticks take longer to produce offspring, and when the mean annual degree-days are < 0°C adult mortality exceeds fecundity, preventing a tick population from establishing in an area (Ogden et al. 2006).

### Projected Future for the Deer Tick

The deer tick occurs in parts of southern Ontario, and along the Ontario-Minnesota border region, but attains its highest density in the northeastern United States. This geographical position, combined with its tendency to disperse on migrating birds, suggests that deer ticks are poised to rapidly expand into central and northern Ontario as winter temperatures warm (Brownstein et al. 2005).

Ogden et al. (2006) have projected the mean annual degree-days < 0°C to show that under both the A2 and B2 scenarios, the range of deer ticks should encompass most of the heavily populated regions of Ontario (everything south of central Ontario) by the 2020s. In an A2 world, deer ticks may reach James Bay by the 2080s. In a B2 world, the ticks could reach a latitude encompassing Red Lake, Hearst, and Cochrane by the 2080s.

### Mitigation and Adaptation

The establishment of deer ticks in central and northern Ontario will likely cause Lyme disease to emerge in these regions because the small rodent species that host *Borrelia burgdorferi* are widespread throughout Ontario. Ontario Parks should expect the incursion of deer ticks into northern parks and prepare adequate education programs for visitors. Similarly, Ontarians who work outdoors should be educated about risks.

Lyme disease is but one example of many human diseases that may spread north into Ontario or increase in incidence as a result of climate warming. Two other examples include: epidemic typhus, which is carried by a tick (*Rickettsia prowazekii*) that infects the southern flying squirrel and is currently present on the eastern seaboard of the United States, as far north as Pennsylvania (Bozeman et al. 1975); and West Nile virus, which occurs in Ontario but appears to have a higher incidence farther south in the United States where adult mosquitoes can overwinter due to warmer temperatures. Ontarians should begin to prepare for increased incidence of these diseases through education.

## Contraction: Moose

The sight of a moose (*Alces alces*) is a classic part of the outdoors experience in Ontario. Ontario's moose population is estimated at about 114 000. Aside from serving as a source of food, study, and recreation, moose

are an economically important species, generating over $500 million per year in hunting revenue across Canada. Moose hunting within the province is regulated by the MNR in accordance with the Fish and Wildlife Conservation Act of 1997.

Projections suggest that climate change will affect moose habitat through increased temperatures, changes in precipitation, and changes to fire regimes resulting in a decrease in mature stands used for cover (Thompson et al. 1998, Murray et al. 2006). Even though moose reduce heat stress by taking shelter at temperatures above 14°C, they cannot withstand excessive heat for extended periods (Dussault et al. 2004). Precipitation can influence moose foraging by changing the quality (Bo and Hjeljord 1991) and accessibility (Post et al. 1999, Post and Stenseth 1999) of forage in both winter and summer. In addition to habitat modification, there are several ways in which climate change may alter the current moose range by altering their demography.

## Climate and Moose Demography

Moose abundance is influenced by snow accumulation in previous winters (Mech et al. 1987, Post and Stenseth 1998), wolf predation, and density-dependent feedback (e.g., competition for food; Messier 1991, Post and Stenseth 1998). All of these factors are themselves affected by large-scale climatic fluctuations such as the North Atlantic Oscillation (NAO; Post and Stenseth 1998). The NAO is a fluctuation in atmospheric pressure that determines winter temperatures and precipitation in North America and Europe. Moose numbers tend to decline 2 years after warm, wet years (Post and Stenseth 1998, Post and Stenseth 1999), suggesting that they may decline along the southern edge of their range as precipitation around Lake Superior and winter temperatures across the province increase.

### *Reproduction*

Weather may affect reproductive success by decreasing the survival of calves or influencing a mother's condition during pregnancy (Mech et al. 1987, Post and Stenseth 1999). Greater snow depth and warm June temperatures during the year of birth have a lasting negative impact on the body mass of moose, and may therefore delay maturity and affect fecundity and access to mates (Solberg et al. 2004). The two-year lag of declines in response to the NAO may be from effects on early development and therefore future fecundity of females born in warmer, wetter winters (Post and Stenseth 1998). In other words, the body condition of breeding female moose is partly determined by the weather during their birth year, and this legacy influences their fecundity.

### *Predation*

Wolves are the primary predators of moose and have a strong effect on moose population dynamics (Post and Stenseth 1998). Although moose are well adapted to travelling in deep snow, calves and older moose suffer higher mortality due to wolf predation in snowy years (Post et al. 1999). A similar effect has been observed between the North Pacific Oscillation (NPO) and wolf-elk interactions in Banff (Hebblewhite 2005). Increased mortality can be explained by greater success of wolves hunting in larger packs in snowy years (Post and Stenseth 1998). Over the next century, winter precipitation is expected to increase in areas adjacent to Lake Superior, and decrease in areas to the east and north. Higher wolf predation in snowier areas may facilitate declines, and promote expansion into areas farther north where snow accumulation is expected to decrease.

### *Parasites*

Parasites are another possible cause of moose declines in southern areas where moose may increasingly come into contact with deer. Meningeal worm (*Paralaphostrongylus tenius)* is a common, non-lethal parasite of deer that can be lethal to moose. At present, deer occur in areas with an annual mean temperature of 4° to 6°C, depending on snow accumulation (Thompson et al. 1998). As the province warms and deer invade moose

range, there is potential for an increased incidence of parasite transmission to moose, resulting in a rise in moose mortality (Thompson et al. 1998, Racey 2005). Murray et al. (2006) found that moose at the south of their range in Minnesota had high mortality due to infection by *P. tenuis* and liver fluke (*Fascioloides magna*). They concluded that increased temperatures in Minnesota had increased contact between deer and moose and subsequent parasitism of moose. Moose may also be indirectly affected by canine parvovirus (CPV) outbreaks in wolves. When wolf numbers on Isle Royale, Michigan, declined due to an outbreak of CPV, regulation of the moose population shifted from a top-down to a bottom-up process (Wilmers et al. 2006). In this case, climate had a stronger effect on the moose population once numbers were being regulated by moose forage (balsam fir, *Abies balsamea*) rather than wolf predation (Wilmers et al. 2006).

#### *Nutrition*

Murray et al. (2006) speculated that climate warming acted in concert with both parasitism and malnutrition to increase moose mortality at the southern edge of their range. They suggested that increased heat stress could cause malnutrition, which would lead to immunosuppression and a subsequent increase in parasitism.

### Projected Future of Moose in Ontario

White-tailed deer are projected to expand their range northwards deeper into moose territory as temperatures increase (Thompson et al. 1998). Moose are expected to decline along the southern parts of their range, both in response to increased summer temperature and increased incidence of parasitism (Thompson et al. 1998, Racey 2005, Murray et al. 2006). Although moose can deal with high temperatures for short periods of time, they may not be able to survive in areas where temperatures exceed 14°C for long periods. All of southern Ontario and much of northern Ontario have already experienced summer average temperatures between 15°C and 20°C. Summer average temperatures are expected to increase 3 to 6°C by 2100 under the A2 and 3 to 5°C under the B2 scenario (Colombo et al. 2007), both of which will increase the probability of heat stress in moose.

In addition, moose may also face increased pressure from wolf predation in areas with marked increases in snowfall. Cold weather precipitation in the areas of Wawa to Manitouwadge as well as along the northwest shore of Lake Superior is projected to increase by 10 to 30% over the coming century under both the A2 and B2 scenarios (Colombo et al. 2007). Mech et al. (1987) have suggested that moose populations are less stable when snow accumulation exceeds 361 cm per year.

### Mitigation and Adaptation

Moose management in Ontario is based on aerial counts and habitat and hunter surveys. In response to declines in eastern Ontario, the hunting regulations in Wildlife Management Units 48, 55A, 55B, and 57 were recently amended based on input from the Eastern Ontario Moose Management Round Table. Harvest of calves is now limited by a tag draw, hunters are required to report on hunting effort and register kills, and bow hunting is being encouraged. As moose range contracts in response to changing climate, MNR may need to implement similar measures across a wider area. Ultimately, hunters at the current southern boundary of moose range may have to switch to hunting deer or travel north to continue hunting moose.

## Phenology

Life cycle stages, such as flowering and migration, are regulated by day length, genetics, or environmental cues (Bradley et al. 1999). Phenology is the study of the relationship between climate and the timing of these life cycle stages. A species' phenology may be cued by threshold temperatures, increases or decreases in temperature or precipitation, or cumulative values such as the number of days during which temperature exceeds a certain value. Climate change may decouple life cycle events that are triggered by different cues, such as photoperiod and temperature. Phenological adjustment may affect abundance by influencing reproductive

success, or the ability to accumulate energy stores before hibernation. Advances in the timing of life cycle stages may allow species to take advantage of new habitats, or exclude them from previously suitable ones.

### Leaf-out

Bud break and leaf-out of trees is regulated by degree days (the number of days over a certain temperature). Tree canopies develop earlier in warmer years, which allows them more time to grow because their leaves seem to fall at about the same time every year, regardless of weather conditions (Richardson et al. 2006). An earlier onset of spring farther north might allow trees to expand north in areas where appropriate soil types and hydrological regimes exist.

### Migration

The migration patterns of many species are tied to temperature and precipitation. For example, British newts are migrating to breeding ponds earlier, resulting in earlier reproduction (Beebee 1995). Numerous bird species, especially short-distance migrants, are returning earlier from their wintering grounds than they have in the past (Bradley et al. 1999, Wilson et al. 2000, Butler 2003, Parmesan and Yohe 2003, Murphy-Klassen et al. 2005). Although this may allow some species to breed earlier, it is not necessarily beneficial. For example, snow accumulation has increased in Colorado, so American Robins (*Turdus migratorius*) arriving earlier are unable to find food (Inouye et al. 2000). Climate change may cause decoupling between a bird species and its prey (e.g., peaks in insect abundance) if the prey is more responsive to temperature changes. For example, birds may suffer lower reproductive success if they arrive too late to lay eggs that will hatch when caterpillar abundance is highest (Visser et al. 1998).

### Reproduction

North American amphibians are also affected by warmer spring temperatures. Spring Peepers (*Hyla crucifer*) breed earlier in warmer years (Blaustein et al. 2001), and many frog species have advanced dates of calling in spring (Gibbs and Breisch 2001). Birds are also showing trends towards earlier breeding (McCleery and Perrins 1998). Early reproduction may give offspring more time to grow before hibernating, but may have deleterious effects on body condition of adults (Carey and Alexander 2003). If earlier reproduction results in increased success, dispersal of increasing populations may lead to range expansions.

## Expansion: Eastern Bluebird

Climate change can affect migratory birds in many ways, including altering their reproductive success, population size, distribution, and the timing of breeding and migration (Price and Glick 2002, Both et al. 2004, Crick 2004). The Eastern Bluebird (*Sialia sialis*) is an example of one of the many bird species that is now migrating (Butler 2003) and breeding (Torti and Dunn 2005) earlier as a result of increasingly milder spring temperatures.

Eastern Bluebirds live in open habitats, where they feed on insects during the breeding season and fruits later in the summer. They lay 1 to 5 broods per year in natural or man-made cavities in open habitat such as fields, orchards, cutovers, and burned areas (Gowaty and Plissner 1998). The Eastern Bluebird is a short-distance migrant, overwintering in the southern United States and Mexico rather than travelling to the neotropics (Gowaty and Plissner 1998, Butler 2003).

### Climate and Bluebird Phenology

The phenology of both migration and egg laying determine the timing of hatching, and therefore bluebird reproductive success. Like many birds, Eastern Bluebirds time egg laying to ensure that their offspring hatch

during a period when insects are available as food for the chicks (Torti and Dunn 2005). Insect abundance reaches its peak early in warm springs, which means that birds must breed earlier as well (Butler 2003, Torti and Dunn 2005).

### *Migration*

Many avian species now return to their breeding grounds earlier in spring due to milder temperatures (Butler 2003, Crick 2004). In eastern North America, short-distance migrants are arriving on the breeding grounds 13 days earlier, which is 9 days earlier than those who migrate to the neotropics (Butler 2003). Short-distance migrants therefore experience more warm days than long-distance migrants under a warming climate and are at a selective advantage due to this disproportionality (Butler 2003).

The timing of fall migration depends on the length of the reproductive period, conditions on the breeding grounds, and expected conditions along the migratory route and in the wintering grounds (Jenni and Kéry 2003). Some short-distance migrants in Europe now begin their fall migration earlier (Jenni and Kéry 2003), and some have even switched their wintering grounds. For example, in some parts of their range, short-distance migrants, including bluebirds, have begun overwintering in the northeastern U.S. (Butler 2003). In future, it is possible that bluebirds will overwinter in parts of Ontario where the average January temperature stays above -6.7°C. Delaying or foregoing fall migration could enable these birds to breed earlier and produce more broods per year (Jenni and Kéry 2003).

### *Breeding*

Once the bluebirds return to their breeding grounds they establish a territory, find a mate, build a nest, and rear their offspring. Eastern Bluebirds at the northern limit of their range have time to produce 1 to 3 clutches, whereas those in the south can produce up to 5 clutches (Gowarty and Plissner 1998). It takes about 3 months to produce the first brood, and a little more than 2 months for each additional brood (Table 1). Earlier spring arrival would allow the birds to begin breeding earlier and for longer, possibly resulting in an extra brood.

Birds time the hatching of their young with peak insect abundance in several ways, including adjusting the date that egg-laying begins, the number of eggs laid, and the initiation of incubation once laying is complete (Dunn and Winkler 1999, Cresswell and McCleery 2003). Across North America, Eastern Bluebirds now lay eggs 4 days earlier than in the 1970s, probably due to earlier peaks in insect abundance (Torti and Dunn 2005).

Eastern Bluebirds now arrive in Ontario between mid-March and early April, and depart between mid-September and mid-November. Extending the breeding period by adjusting the timing of migration and laying may allow bluebirds to lay additional broods, increasing the number of fledged young in a year. Clutch size tends to

***Table 1.*** *Eastern Bluebird (Sialia sialis) breeding schedule, as described by Gowaty and Plissner (1998).*

| How long does it take to produce a single brood? | | |
|---|---|---|
| Time frame | Activity | Notes |
| 0 – 7 days | find a mate | may have bonded with a mate on the wintering grounds |
| 0 – 21 days | build a nest | 1-3 weeks to build new nest, <1day to reuse former nest |
| 5 – 9 days | initiate egg-laying | first egg laid to synchronize hatching with food peak |
| 3 – 7 days | egg-laying | lay one egg per day, may adjust number to tune hatching |
| 11 – 19 days | incubate | |
| 17 – 20 days | fledge | |
| 0 – 14 days | interbrood interval | generally wait 2 weeks between broods |
| 36-97 days | total time | depending on brood number, latitude, and season |

be larger both in warmer years and in earlier broods (Torti and Dunn 2005). As the population increases due to higher breeding success, competition for food and nesting sites will increase. This in turn may encourage birds to disperse into new areas and expand their range northwards. Observations recorded during development of Ontario's second Breeding Bird Atlas indicated they occur in many new locations in northern Ontario compared to when the first atlas was developed. The new locations may represent an expansion into the north but may also be a result of a higher intensity of searching (Ontario Breeding Bird Atlas, unpubl. data).

## Projected Future of Bluebirds in Ontario

Grassland habitat in eastern North America is expected to increase as a result of increased frequency and intensity of forest disturbance (Bachelet and Neilson 2000). If bluebird abundance and dispersal does increase as a result of a longer breeding season, they will be able expand their range northwards by taking advantage of more open habitat.

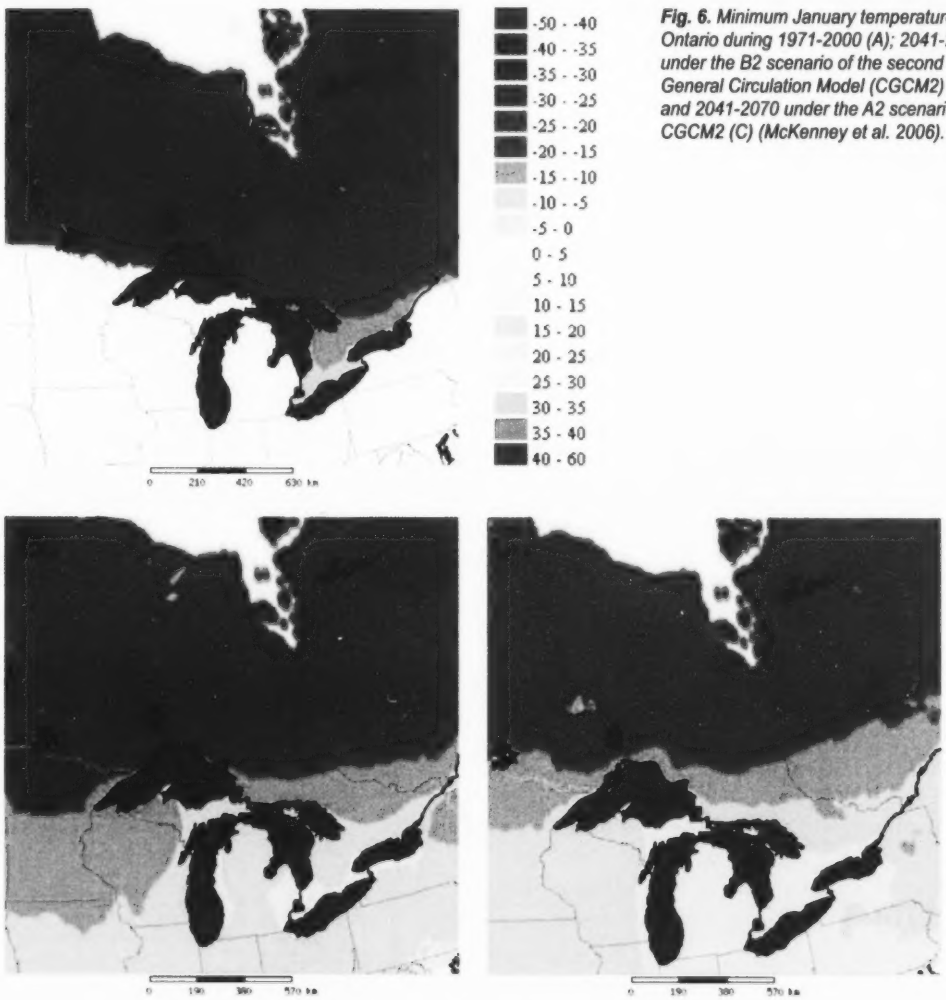


***Fig. 6.*** *Minimum January temperatures in Ontario during 1971-2000 (A); 2041-2070 under the B2 scenario of the second Canadian General Circulation Model (CGCM2) (B); and 2041-2070 under the A2 scenario of the CGCM2 (C) (McKenney et al. 2006).*

Eastern Bluebirds may further advance breeding times by shortening migration and overwintering in some parts of Ontario. The winter range of Eastern Bluebirds is limited to areas where the average January temperature stays above -6.7°C (Root 1988; Fig. 6a). Under the A2 scenario, it is predicted that the minimum January temperature for much of southern Ontario (south from Midland and Gananoque) will be 0 to -5°C by the year 2070 (Fig 6c). Under the B2 scenario, temperatures are projected to be suitable for overwintering bluebirds in much of southwestern Ontario, and along the north shore of Lake Ontario as early as 2041 to 2070 (Fig. 6b).

### Mitigation and Adaptation

Eastern Bluebird migration is not well understood because it is difficult to distinguish residents from migrants in overwintering areas (Gowaty and Plissner 1998). Future research could improve understanding of migration cues and the consequences of global warming for this and other migratory birds.

Establishing nest boxes in suitable habitat will help bluebirds colonize new areas. Nest boxes should be placed in open areas, >10 m above ground to reduce competition with other cavity-nesting birds (Gowaty and Plissner 1998). Land managers can leave snags standing as a natural source of nesting habitat as well (Gowarty and Plissner 1998). Active habitat management can assist the colonization of sites by some species capable of expanding their geographic ranges.

## Contraction: Polar Bear

In July or early August, polar bears (*Ursus maritimus*) of the Southern Hudson Bay population come ashore in Ontario as the annual ice of Hudson Bay breaks up and melts away. The bears spend the next 4 to 8 months living on body fat accumulated while hunting seals and other marine mammals from the sea ice. The southern Hudson Bay population is currently estimated at 1000 bears (COSEWIC 2002), and is managed jointly by Ontario, Quebec, and Nunavut. Polar bears are listed as a species of Special Concern federally and provincially, and are also listed on Appendix II of CITES (Convention on International Trade in Endangered Species).

The nature of Arctic ice has been changing in recent years, and this will probably continue as a result of climate change. Not only is ice breaking up earlier and forming later (Parkinson and Cavalieri 2002), it is also thinner than it was 50 years ago (Rothrock et al. 1999). Changes in the structure and duration of sea ice will have consequences for polar bears and the Arctic food web upon which they rely.

### Ice Phenology and Polar Bears

Ontario's polar bears depend on sea ice in Hudson Bay for hunting and mating. They gain the most weight in April, May, and June, just prior to ice breakup when newborn and newly weaned ringed seals are abundant (Stirling et al. 1999, Derocher et al. 2004, Rosing-Asvid 2006). The timing of ice breakup and emergence of open water dictate when bears leave the sea ice for coastal habitats (Stirling et al. 2004). The ice-free period in the southern Hudson Bay typically lasts from July or August to November or December. The timing of breakup varies among years but generally occurs between early July and mid-August (Stirling et al 1999, Parkinson and Cavalieri 2002, Stirling et al. 2004). In October, as the rest of the bears congregate along shores in anticipation of freeze-up, pregnant females travel inland and enter maternity dens for 8 months (Kolenosky et al. 1992, Stirling et al. 1999).

Polar bears will be affected by changes in the timing of ice break-up and freeze-up, and changes in the size of the sea ice platform. The breakup of sea ice is now occurring 3 weeks earlier along the western shore of the Hudson Bay, and may be responsible for declines in the Western Hudson Bay population of polar bears. The bears must come ashore earlier, leaving them in poorer condition, and resulting in lower reproductive success (Stirling et al. 1999). Ontario's polar bears appear to be facing a similar fate due to an increase in the ice-free period in southern Hudson Bay (Obbard et al. 2006).

### *Hunting*

Polar bears in Hudson Bay primarily hunt ringed seal, but also feed on other seal species and occasionally walrus (Kolenosky et al. 1992, Derocher et al. 2004). Weather affects the survival of ringed seal pups and the dates that they are most vulnerable to polar bear predation (Stirling and Smith 2004, Rosing-Asvid 2006). The pups are born in snow lairs on sea ice in early April and are weaned in about 6 weeks. Warmer temperatures and rain can cause the snow lairs to collapse, leaving pups exposed to cold and predation (Stirling and Smith 2004, Rosing-Asvid 2006). Warmer, wetter springs make it easier for polar bears to find seal pups in early spring but also leaves fewer pups available right before break-up in July when pups are larger and more valuable to bears putting on weight before the ice-free period (Rosing-Asvid 2006).

It is difficult to predict how climate change will affect all aspects of the polar bear diet. Reduction of ice cover may change the behaviour and distribution of prey, increase competition at good hunting sites, and decrease the number of carcasses left by older bears for younger bears to scavenge on (Derocher et al. 2004). In addition, adult males could hunt female and young bears at den sites and on the sea ice (Amstrup et al. 2006).

### *Reproduction*

Polar bears from the Southern Hudson Bay population tend to return to the same coastal areas every summer, and females tend to den in the areas where they are born (Kolenosky et al. 1992, Stirling et al. 2004). The Southern Hudson Bay population stays on sea ice longer than bears in the western population because the ice near the southern bears' summer grounds is the last to melt in Hudson Bay (Kolenosky et al. 1992, Stirling et al. 2004). If the extent of sea ice decreases or breaks-up were earlier, these bears will be forced to either swim farther distances or leave the ice platform earlier to reach their den sites. In addition to using more of their energy stores, polar bears may be more susceptible to drowning if forced to swim long distances in rough weather (Monnett and Gleason 2006, Obbard et al. 2006).

Fat stored before breakup must support females and their nursing cubs until the young bears are old enough to leave the den in spring (Kolenosky et al. 1992, Stirling et al. 1999, Derocher et al. 2004). Females in poorer condition may not produce cubs until older, may produce fewer cubs less often, and their offspring may have lower survival rates (Stirling et al. 1999, Derocher et al. 2004). During the ice-free period bears lose approximately 0.85 to 0.9 kg/day (Derocher et al. 2004). If the ice-free period increases by 0.5 days per year, as it has in the western Hudson Bay, the average female in 100 years will be below the weight for successful reproduction (189 kg) (Derocher et al. 2004).

## Projected Future of Polar Bears in Ontario

Climate change may cause a northward shift in polar bear range (Derocher et al. 2004). This could mean extirpation of the species from Ontario, since it is at the southern-most limit of its range in the Hudson and James bays. Detection of initial population declines may be delayed since polar bears are a long-lived species and the odd cold year may mask the effects of overall warming (Derocher et al. 2004).

The extent of Arctic sea ice during June-July and November-December has declined since 1971 (Parkinson and Cavalieri 2002). Based on the first generation coupled general circulation model (CGCM 1), under a doubling of $CO_2$ a combination of rising temperatures and increased precipitation during ice breakup and freeze-up may result in the disappearance of sea ice from the southern Hudson Bay by as early as 2100 (Gough and Wolfe 2001). The only remaining ice would be located in Foxe Basin, far from the Southern Hudson Bay shoreline (Gough and Wolfe 2001). Based on the more recent general circulation model (GCM II), under a doubling of $CO_2$ breakup would occur 1 month earlier and freeze-up 1 month later, resulting in an increase of the ice-free season from 3 to 5 months and less ice overall during winter (Gough and Wolfe 2001). This would give bears less time to fatten up on recently weaned ringed seal pups before heading for land and would mean that they would have farther to swim to reach their denning sites.

Even if ice conditions remain the same, rising temperatures and increased precipitation will have other negative infuences on polar bear habitat. Melting of up to 50% of permafrost (Gough and Leung 2002) and decreased snowfall (Colombo et al. 2007) could reduce the number of suitable den sites. In both an A2 and a B2 world, projected increases in temperature (e.g., A2= 9 to 10°C in winter and 5 to 6°C in summer, Colombo et al. 2007) will significantly reduce denning habitat.

### Mitigation and Adaptation

Under the International Agreement on the Conservation of Polar Bears and their Habitat, Canada has accepted responsibility for managing polar bears in accordance with sound conservation practices based on the best available scientific knowledge. More research is needed to determine how polar bears, their prey, and the rest of the Arctic foodweb may respond to climate change (Derocher et al. 2004).

## Genetics

During past periods of climate change, species enlarged or shifted ranges by expanding along some boundaries and contracting along others (Hampe and Petit 2005). Increased dispersal ability during periods of range expansion may increase genetic diversity and help spread benefical genotypes throughout the population (Hewitt and Nichols 2005). In contrast, genetic diversity may decrease in the periphery of the distribution. For example, the leading edge of range expansion may be subject to a founding effect and population bottlenecks which can cause declines in genetic diversity due to inbreeding of colonizers isolated from the core population (Hewitt and Nichols 2005). In addition, genetic diversity is lost when a population is extirpated at the trailing or contracting edge (Hewitt and Nichols 2005).

### Inbreeding

Inbreeding depression can result when closely related individuals breed over several generations, increasing the risk of recessive traits and mutations that can reduce fitness. Large population size and high density of pollinators or mates decreases the chances of inbreeding depression within a population. Species or populations that become isolated due to climate change, fragmentation, or a combination of factors may be susceptible to inbreeding depression, particularly when the population is small. Inbreeding depression may also decrease the ability of a species to adjust to changing climate. For example, inbred populations of Red-cockaded Woodpeckers (*Picoides borealis*) in the southeastern U.S. do not alter egg laying in warmer years (Inkley et al. 2004).

### Hybridization

Hybridization refers to the interbreeding of genetically distinct species or populations. Climate change might increase rates of hybridization between populations as they shift in response to climate. For example, common or invasive species may hybridize with rarer species, reducing the fitness of populations or even resulting in extirpation or extinction of the rare species (Rhymer and Simberloff 1996). Hybrids can have reduced fitness (outbreeding depression) due to a loss of local adaptation or co-adapted gene complexes (Rhymer and Simberloff 1996). Conversely, hybridization may increase an organism's ability to cope with climate change, or otherwise increase fitness (hybrid vigour). For example, fishers (*Martes pennanti*) in Ontario appear to exhibit hybrid vigour between recolonizing populations (Carr et al. 2007b). The emergence date of budworm (*Choristoneura* spp.) is more responsive to spring temperature when it hybridizes with a congener (Volney and Fleming 2000).

### Adaptation

Though their historical ranges fluctuated during ice ages and interglacial periods, many species are adapted to conditions in their current habitats (i.e., local adaptation; Davis and Shaw 2001). For example, there are three lynx-hare cycles in North America, each adapted to the snow depth in its area (Stenseth et al. 2004). During

periods of change, dispersal of plants and animals contributes to gene flow, providing a source of variation and pre-adapted genotypes. Natural selection kills off poorly adapted individuals (Davis and Shaw 2001).

In the past, some species have evolved new climatic tolerances, but many of the genetic changes observed to date are related to phenological traits (Davis and Shaw 2001, Bradshaw and Holzapfel 2006). Great tits (*Parus major*, a European passerine) with greater phenotypic plasticity have a higher chance of survival, and in turn are passing on the ability to deal with fluctuating environmental conditions (Nussey et al. 2005). Species may also adapt to changing climate by increasing their dispersal ability. Insects undergoing range expansion can produce individuals able to take advantage of a greater variety of habitats or travel long distances to colonize new habitats (Thomas et al. 2001).

Although some species may be able to adaptively respond to climate change, the required rate of change will likely be too great for many species to adapt, especially larger, longer-lived species (Bradshaw and Holzapfel 2001, Davis and Shaw 2001). Evolution over shorter time spans is often coupled with anthropogenic forces of habitat loss, overharvesting, and the introduction of exotic species (Stockwell et al. 2003). For example, exotic species are often introduced at disturbed sites, persisting in small numbers until they have adapted to local conditions and can increase in numbers (Stockwell et al. 2003). Therefore, in such cases natural resource managers should concentrate eradication efforts on the earliest phases of an invasion, before the species has time to adapt (Stockwell et al. 2003).

## Expansion: Red Squirrel

Red squirrels (*Tamiasciurus hudsonicus*) are abundant rodents that are active year round. They store seeds from spruce and pine cones to use as a winter food source, and are highly territorial, watching over their stored food throughout the day. Their loud, scolding trill is a familiar sound to trespassers.

### Speciation Over Geologic Time

The squirrel family (Sciuridae) is one of the most diverse mammalian families. Beginning in the northern hemisphere 36 million years ago, squirrels diverged from other rodents, and began dispersing around the globe (Mercer and Roth 2003). High diversification has resulted in dozens of Genera, represented in 5 major clades, including 3 main forms: flying squirrels, ground squirrels, and tree squirrels (Mercer and Roth 2003). The diversity and global range of the squirrel family indicates that the group has been able to respond adaptively to historic changes in climate.

### Microevolution Over Short Time Scales

Climate warming increased the abundance of white spruce cones in the Yukon from 1989 to 1998, such that the number of cones available to female red squirrels (*Tamiasciurus hudsonicus*) in their lifetime increased about 35% during that time. The increased availability of food and warmer spring temperatures has caused female squirrels to advance the date at which they give birth by 18 days (from 8 May to 19 April) during these 10 years (or 6 days per generation) (Réale et al. 2003). Some of this change is due to phenotypic plasticity, but Réale et al. (2003) measured the heritability of parturition dates and demonstrated an inherited (genetic) component to this response. About 13% of the change in parturition date is due to heritable differences in this trait that are passed on from mothers to offspring (Berteaux et al. 2004).

### Projected Future of Red Squirrels in Ontario

Red squirrels have a large geographic range, occuring even as far south as Arizona, and thus appear to have a large climate envelope. A key component of their habitat suitability appears to be the availability of spruce or pine cones (Obbard 1987). As their habitats change in response to changing climate, the carrying capacity of those habitats for squirrels will also change. The geographic range of red squirrels may not contract however,

and may even expand. This could happen as suitable habitat expands to the north of their current range, and phenotypic and evolutionary plasticity allows squirrels to remain in much of their occupied habitat along the southern edge of their range.

In Ontario, red squirrels are ubiquitous, and this may not change as a result of climate warming. Currently however, red squirrels in much of Ontario eat primarily spruce cones. Spruce trees are expected to become less abundant in much of the province as climate warms, whereas pine trees may become more abundant (Iverson and Prasad 2001). This type of transition will necessitate a switch by red squirrels from spruce to pine cones in parts of their provincial distribution. Such a switch appears feasible, since in many parts of their range, red squirrels already specialize on pine nuts (Obbard 1987). The overall effect of habitat transitions in Ontario related to climate warming may be to change the abundance of red squirrels, but not the range, since they occur throughout the province and may continue to do so.

### *Mitigation and Adaptation*

Given the apparent genetic and plastic responses of red squirrels to climate change, it would appear that this is a case where little mitigation or adaptation by Ontarians is required. An action that is required however is to understand which species are not likely to have genetic and plastic responses to global change. Species that cannot respond genetically are those that do not have high genetic variability for fitness-related traits (Berteaux et al. 2004). Phenotypic plasticity is probably best indicated by large geographic range size. Taken together, these ideas suggest that species with small geographic ranges and low genetic variability for fitness-related traits are most at risk from global climate change.

## Range Contraction: Black-capped Chickadee

The Black-capped Chickadee (*Poecile atricapillus*) is a symbol of Canadian winter, and one of Ontario's most common and beloved songbirds. These non-migratory birds form gregarious winter flocks that can often be heard in the woods and are easily attracted by 'pishing' birders.

### Hybridization with the Carolina Chickadee

One mechanism of genetic change in response to climate warming is hybridization, where two closely related species interbreed. Depending on the relatedness of the species, the resulting hybrid offspring may be sterile, viable with increased fitness (hybrid vigour), or viable with reduced fitness (outbreeding depression) (Rhymer and Simberloff 1996). If hybridization is extensive enough that a parental species is completely replaced by a hybrid one, the parental species will be extinct. This process is known as extinction through hybridization (Rhymer and Simberloff 1996).

The Carolina Chickadee (*Poecile carolinensis*) has been shown, through a series of experiments and observational studies, to hybridize with the Black-capped Chickadee (Bronson et al. 2003a, b, 2005; Curry 2005). Mixed parents have reduced hatching success, and their offspring have reduced reproductive success. Thus, this hybridization appears to be a case of outbreeding depression. The current hybrid zone between these two species occurs in Ohio, and Bronson et al. (2005) have shown that there is a trough in hatching success along a transect that spans this hybrid zone.

### Projected Future for Black-capped Chickadees in Ontario

As its name suggests, the geographic range of the Carolina Chickadee is centred in the southeastern U.S. However, this species has been steadily expanding its range to the north, presumably in response to climate change. A recent estimate suggests that its northern range boundary has shifted north by about 2 km per year for each of the last 26 years (Hitch and Leberg 2007). As winter temperatures continue to increase, it is reasonable to

expect that this rate of range expansion will increase as well. Therefore, we expect that the hybrid zone between the Carolina and Black-capped Chickadee will expand north from Ohio into Ontario within a few years.

Eventually, hybrid chickadees will replace the Black-capped Chickadee in southern parts of Ontario. The familiar whistling chickadee song will be changed. The songs of hybrids are different in that they are more variable, with males singing either both or only one of the parental species' whistled calls (Rossano 2003). Most importantly though, we may have fewer chickadees overall since the hybrids appear to exhibit outbreeding depression.

### Mitigation and Adaptation

Hybridization between species is expected to increase in response to a warming climate due to increased sympatry (or overlap) between formerly parapatric (non-overlapping) species. Recent sympatry is a mechanism for increasing hybridization (Rhymer and Simberloff 1996). Management response to changes in the distribution and abundance of species and the emergence of hybrids likely will require a variety of initiatives. For example, as species distribution maps change, field and song guides will require updating.

In the case of songbirds such as chickadees, it appears that little can be done to mitigate the impact of climate change. Many other species will face increased hybridization as well. For example, the southern flying squirrel (*Glaucomys volans*) is expanding its range north in Ontario and recent sympatry may create conditions for hybridization with the northern flying squirrel (*G. sabrinus*) (Bowman et al. 2005). Similarly, we expect the bobcat (*Lynx rufus*), which can hybridize with lynx (*Lynx canadensis*) (Schwartz et al. 2004), to also expand its range north.

## Terrestrial Communities and Climate Change

Communities are commonly defined in ecology as groups of interacting populations (Ricklefs 1990). Although there may be co-evolution of species within communities, natural selection occurs in populations, not communities. Moreover, rather than being closed entities divided by sharp ecotonal boundaries, communities are predominantly open, with intergrading species abundances (Fig. 7; Whitaker 1956, Ricklefs 1990). Therefore, communities are *ad hoc* collections of interacting species rather than emergent systems (Ricklefs 1990). Here, we take the view that climate change will affect populations of species, and its impacts on communities largely will be through effects on interactions between these populations, rather than on community-level properties.

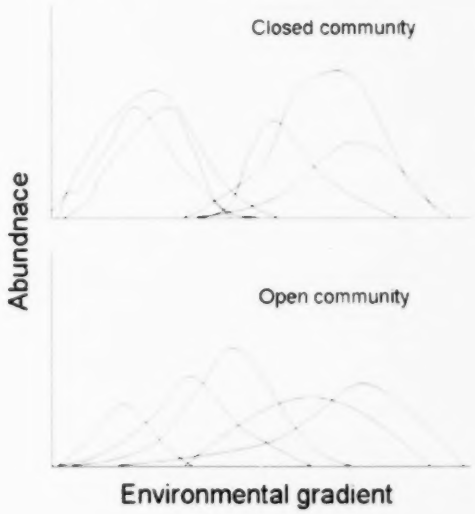


***Fig. 7.*** *Schematic depiction of open versus closed communities, where the lines represent abundance of individuals of different species along an environmental gradient. Closed communities can be identified by sharp ecotonal boundaries and highly overlapping species distributions. They are more consistent with the notion of system-level properties than open communities. In this review, we have taken the view that communities predominantly have open structures. Redrawn after Ricklefs (1990).*

## Biotic Interactions

Climate may affect community components (populations) individually, or the interaction between or among these components, and these effects are difficult to predict (Schmitz et al. 2003). It is clear that changes in patterns and rates of migration in response to rapid climate change will vary by species (Davis and Shaw 2001). As a general rule (from which there are exceptions), species whose range limits occur in the southern parts of Ontario (or south of Ontario) will move north with their climate envelopes as climates and habitats become suitable. Many of these species will become established north of their current ranges (Hampe and Petit 2005). Similarly, species whose southern range limits currently occur in Ontario will likely experience northward contractions of these southern boundaries.

As species expand their ranges north, they will encounter naïve prey and fewer competitors resulting in high rates of increase and large population densities at the edge of the northern range boundary (Caughley 1970). Where it occurs, hybridization may dampen or enhance these effects, depending on whether outbreeding depression or hybrid vigour results. At relatively local scales, higher temperatures may be correlated with higher species diversity. For example, Kerr and Packer (1998) found that mammal species richness in Canada is related to temperature as:

Mammal species richness = 1.96 (mean annual temperature) + 38.1 + error

Global diversity however, may decrease despite predictions of this energy model. As colder-adapted species contract their ranges, their extinction risk is increased (Woodward 1992, Kerr and Packer 1998). Also, diversity may be lost if populations cannot shift rapidly enough to keep pace with climate. Although we know that Ontario's biodiversity will change due to global warming, it is unclear how this change will affect ecosytem composition, structure, and function. For example, predator-prey and parasite-host systems may be disrupted, and keystone taxa may disappear from local environments (National Assessment Synthesis Team 2000). It is unknown to what extent empty niches will be filled by invading species.

Four categories of climate change effects on biotic interactions are of particular interest: asymmetries, asynchronies, synergies, and thresholds.

### *Asymmetry*

Projections about the direction of climate change effects on populations and their interactions are complicated by potential asymmetries. For example, the effect of climate warming on migratory birds that breed in Europe depends on the location of their wintering grounds. Birds that winter north of the Sahara desert now delay their autumn departure, whereas birds that winter south of the Sahara now advance the date of their autumn departure (Jenni and Kéry 2003). This is presumably due to the need for long-distance migrants to cross the desert before its seasonal dry period. The net effect of these impacts is that short-distance migrants that breed in Europe appear to benefit from climate change (e.g., by having a longer breeding season), whereas long-distance migrants do not (Jenni and Kéry 2003). The result of climate change will therefore be selection towards short-distance migrants in Europe.

A similar selective advantage appears to occur in species that have potential for rapid rates of spread. This is because species' climate envelopes appear to be rapidly advancing north, but many species cannot migrate quickly enough to keep pace (Malcolm et al. 2002). It appears therefore that rapid climate change will select for species that can rapidly spread, such as many invasive species (Weber 1998, Malcolm et al. 2002).

These asymmetry examples suggest that the effects of climate change are not unidirectional. Instead, they depend on species-specific traits, which means that a sound understanding of species biology will be critical in understanding and accurately predicting the impacts of global warming on individual species.

### *Asynchrony*

The weight of evidence to date suggests that rapid climate change will reduce synchrony between interacting species (Parmesan 2006). This is at least partly explained by the species-specific nature of climate change effects. For example, some insectivorous bird species will have to shift nesting phenology in order to synchronize laying date with the peak abundance of nestling food such as caterpillars (Visser et al. 1998, Visser and Both 2005). These shifts in phenology appear more readily made by invertebrates (i.e., by species that serve as nestling food). Butterflies often rely on a specific food plant, so if plants are unable to move or adapt in response to rapid climate change, some butterfly populations may disappear even though they are mobile enough to keep pace with climate (Petersen 2004). Climate change might decouple population cycles of spruce budworm and organisms that regulate its abundance (parasitoids and predators), resulting in large-scale changes at epidemic levels (Inkley et al. 2004).

Visser and Both (2005) showed that in 7 of 11 cases with adequate data, interacting species are more out of synchrony now due to climate warming than at the start of the studies. This underscores the complexity of changes to biotic interactions caused by rapid global warming.

### *Synergy*

Climate change creates synergistic effects with many other processes. For example, a species may fail to shift its range in concert with a changing climate envelope because of habitat fragmentation (Taylor et al. 1993). Therefore, redistribution of populations to accommodate shifting climates may not be possible in fragmented landscapes, leading to higher extinction rates (Travis 2003, Inkley et al. 2004, Opdam and Wascher 2004). Many forest plant species within highly fragmented landscapes show no or low ability to colonize new habitat patches (most move only a few metres per year). In one study, successful colonization was higher in a more connected landscape, and animal-dispersed species were better able to colonize habitats than those dispersed by other means (Honnay et al. 2002). In Ontario, this climate change-habitat fragmentation synergy will be a particular problem in the south, where habitat fragmentation is more severe. For example, the southern flying squirrel, a forest-obligate species, has spread north only through the contiguous habitats of the Precambrian shield, and not

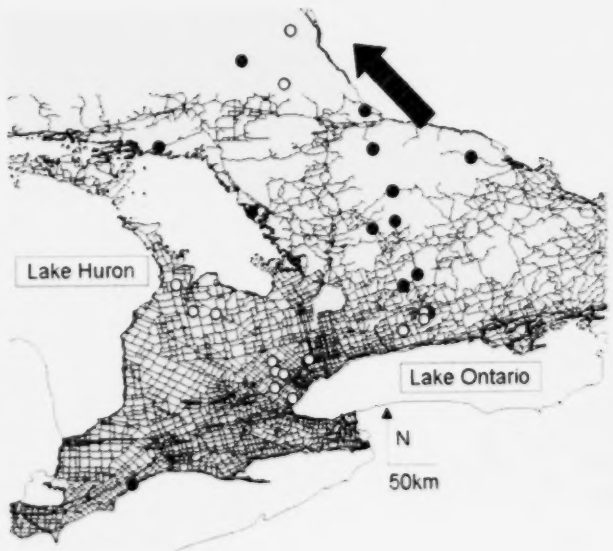


***Fig. 8.*** *Sites where southern flying squirrels (Glaucomys volans) were detected (black circles) versus not detected (white circles) following a range expansion in Ontario. Roads in southern Ontario are depicted as black lines. It appears that the range expansion was limited by road density. If so, this would be an example of a synergy between climate change and habitat fragmentation (from Bowman et al. 2005).*

through the fragmented forests of the southwest (Bowman et al. 2005) (Fig. 8). Southern Ontario is also where most of the province's rare species are, so this synergy will pose an important challenge.

Synergies can also occur between climate and disease. On Isle Royale, the gray wolf (*Canis lupus*) population crashed following an outbreak of parvovirus, resulting in a trophic cascade affecting moose populations and their primary food source: balsam fir (Wilmers et al. 2006). Moose switched from being regulated by wolves to being regulated by food and climate. Climate effects on moose demography doubled after the parvovirus outbreak.

Climate change will alter local ecological conditions in a way that may favour invasive species (Dukes and Mooney 1999). Invasives often have short generation times, and high propagule pressure (i.e., long and frequent dispersal), and these characteristics may be selected for by rapid climate change since species will have to shift with climate (Malcolm et al. 2002). Increasing invasives can potentially reduce global diversity by outcompeting or preying upon native species.

### *Thresholds*

There is some evidence that extinctions due to climate change may occur as threshold phenomena. Hoyle and James (2005) concluded that "there may be an annual average temperature, specific to each endangered species, above which extinction becomes much more likely". They studied the Sinai baton blue butterfly (*Pseudophilotes sinaicus*) and concluded that as the intensity of warming increased in a population model, the importance of warming grew to a threshold where the probability of extinction was markedly increased.

Similarly, threshold phenomena are well known in habitat loss studies (Fahrig 2003). The habitat loss threshold could be exacerbated by synergies between habitat loss (or fragmentation) and climate change. MNR staff will have to be prepared for the possibility of rapid changes in distribution and abundance resulting from non-linearities in system responses (e.g., Fig. 9).

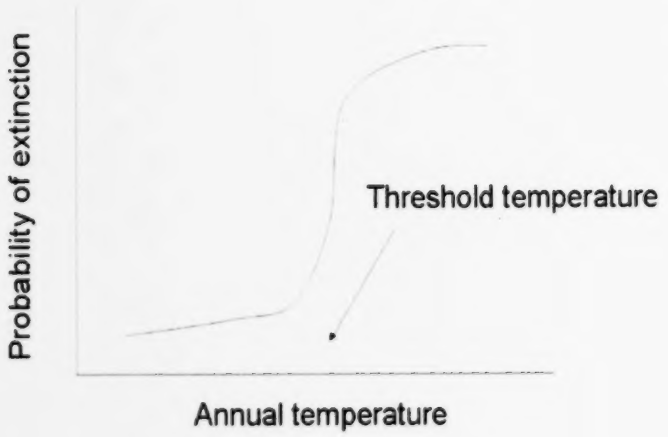


***Fig. 9.*** *Hypothetical example of the relationship between annual temperature and probability of extinction for a species that has an extinction threshold related to temperature.*

***Table 2.*** *Relative risks of climate change associated with certain traits of species in Ontario.*

| Trait | Direction of trait | Relative risk |
|---|---|---|
| Geographic range size | Large | Low |
| | Small | High |
| Genetic variability | High | Low |
| | Low | High |
| Vagility | High | Low |
| | Low | High |
| Location of range boundaries | SBO* | High |
| | NBO** | Low |

*SBO = southern range boundary occurs in Ontario

**NBO = northern range boundary occurs in Ontario

## Conclusions

Although numerous studies indicate significant change to the distribution and abundance of plants and animals is now occurring (Appendix 2), there are significant gaps in our understanding of the effects of climate change.

The asymmetry examples suggest that effects of climate change are not unidirectional. Instead, they depend on species-specific traits. For example, there will likely be selection for species that can disperse far and often. Responses of species will be diverse, and a good knowledge of species biology will be critical in understanding and projecting impacts of global warming on individual species.

Given that every species will respond to climate change in a unique way, there is strong potential for a decrease in the amount of synchrony between interacting species (Parmesan 2006). For example, predator-prey and parasite-host systems may be disrupted. It will therefore be difficult to predict the trajectory of synchronous systems, and hence "communities" under a changing climate. The outcomes will be at least as diverse and complex as the responses of individual species, and probably much more so (Schmitz et al. 2003).

At this time, we can provide some general observations about the effects of climate change (Table 2). It does appear that species with small geographic ranges and low genetic variability for fitness-related traits are most at risk due to global climate change (Berteaux et al. 2004, Schwartz et al. 2006). Conversely, species that are able to migrate rapidly enough to keep pace with changing climate will be least at risk. As a result, there are some obvious taxonomic differences in risk: migratory birds are highly vagile and therefore less at risk than more sedentary organisms such as reptiles and amphibians. Invasive species may also be favoured (Dukes and Mooney 1999). Populations that occur in habitat fragments may be at increased risk of extinction due to the synergistic effects of climate change and habitat fragmentation (Opdam and Wascher 2004).

Generally, the effects of climate change on species in Ontario will depend on the location of their range boundaries (Kerr and Packer 1998). Of species with relatively large geographic ranges, the ones that have northern range boundaries in Ontario will generally benefit from climate change. Species with southern range boundaries in Ontario will generally be selected against. This means that many of our management and conservation activities concerned with species loss should focus on these northern species. Conversely, management actions aimed at issues related to overabundance will be focused on the southern species.

There will be increased incidence of hybridization between species and populations due to the rapid northward shift of some species and resulting increased sympatry. Overall, through these natural and artificial invasions, there is likely to be a genetic homogenization that reduces global biodiversity (McKinney and Lockwood 1999). Although species diversity might be expected to increase in local areas with increasing temperature (Kerr and Packer 1998), the rapid change, along with the asymmetries, asynchronies, and synergies may well offset any potential gains in biodiversity (Kerr and Packer 1998, McKinney and Lockwood 1999). Even without a reduction in overall biodiversity, the constituents of Ontario's biodiversity will change with unknown consequences. We have little knowledge about the relationship between our native biodiversity and ecosystem function.

## Mitigation and Adaptation

Based on our review of potential impacts of climate change on terrestrial communities in Ontario, a number of mitigation and adaptation strategies are available. Examples include, but are not limited to:

### Management

- Address climate change in species-at-risk recovery plans.
- Adjust harvest allocations and seasons of wildlife species to reflect changing carrying capacities and shifting breeding and migration patterns.
- Forest management plans should account for climate change in habitat management plans.
- Increase connectivity between habitats, permitting populations to shift in response to climate.
- Move protected habitats to respond to changes in biodiversity. Mechanisms for this may include new approaches to habitat protection and increased participation of landowners.
- Reassess current approaches to habitat protection and management in the context of a rapidly changing climate.
- Encourage active habitat management, such as the establishment of nest boxes and the protection of cavity trees, to facilitate the colonization of sites by species expanding their ranges.
- Consider translocating sensitive species farther north if inadequate habitat connectivity is blocking the species' redistribution (Honnay et al. 2002).
- In severe cases, establish captive populations of rare species to conserve genetic diversity.
- Where possible, control invasive species.

### Research

- Conduct research to fill several knowledge gaps about species responses to climate change. Appendix 2 identifies peer-reviewed studies of the effects of climate change on Ontario's terrestrial vertebrate species.
- Collect information about basic biology for many species. A particular focus should be paid to traits identified as important in Table 2, such as vagility and genetic variability.
- Collect empirical evidence to assess potential shifts in biotic interactions due to climate warming.
- Species-at-risk and specialist species with small geographic ranges and low genetic variability should be a focus of conservation efforts, including research and monitoring.
- Undertake species vulnerability assessments.
- Identify species and populations that require active human intervention to mitigate losses.
- Acquire longer-term data sets to assess species responses and evaluate dose-response relationships, rather than simple correlational studies (Carey and Alexander 2003).
- Develop models to better understand the complex potential outcomes of climate change on species and their interactions (Schmitz et al. 2003).
- Evaluate potential synergies between species invasions and climate change (McCarty 2001) and habitat fragmentation and climate change (Opdam and Wascher 2004).

- Study genetic variability for fitness-related traits to identify species most at risk from climate change (Berteaux et al. 2004).
- Account for regional differences in climate (McCarty 2001) – climate may affect species interactions differently in different areas. Therefore, research must account for geographical context.
- In a world with rapidly changing biodiversity, we need to develop a better understanding of the role of biodiversity in ecosystem structure and function.

## Adaptation

- Develop policies for management of hybrid species and populations.
- Educate hunters and trappers to adjust to a different climate, and to the suite of changes that results both in the type and amount of wildlife that is harvested, and in the practices used to carry out the harvest (e.g., snowmobile vs all terrain vehicle). The direction and magnitude of these changes will be regional.
- Adjust harvest rates for trapped and hunted species.
- Prepare MNR staff and partners for the possibility of rapid changes in distribution and abundance resulting from non-linearities in system responses.
- Changes in the distribution and abundance of diseases and parasites will have significant implications for natural resource agency programs and the public at large. Identify education and extension requirements and opportunities to help Ontarians adapt.
- Update natural history field guides and other knowledge transfer products to reflect the changing species composition of the province.

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# Appendix 1

A glossary of technical terms used in this report. Adapted from Ayala (1982), Ricklefs (1990), and Sinclair et al. (2006).

| | |
|---|---|
| **Asymmetry** | A quality of effects that are not proportional across species or populations. |
| **Asynchrony** | A discordance between or among processes. |
| **Climate** | The average weather conditions of a defined area. |
| **Climate envelope** | A description of the climate within which a species can persist; related to the fundamental niche. |
| **Climate model** | A quantitative description of the interactions between the atmosphere, oceans, and land surface. Best guesses about these interactions are used to forecast how changing $CO_2$ levels will affect a future world. |
| **Co-adaptation** | A synergy between or among genes reinforced by selection. |
| **Community** | A group of interacting populations. |
| **Demography** | The vital rates of a population; the study of the structure of a population. |
| **Founder effect** | Genetic drift that occurs when a population is founded by a small number of individuals. |
| **Fundamental niche** | The optimal set of resources and conditions that allow a species or population to persist in a particular place. |
| **Hybridization** | Successful interbreeding between two different species, subspecies, or populations. |
| **Hybrid vigor** | Superiority of heterozygotes over homozygotes with respect to a trait. |
| **Inbreeding depression** | Reduction in fitness due to the breeding of closely related organisms. |
| **North Atlantic Oscillation** | A north-south alternation in atmospheric mass that has large-scale effects on weather. |
| **Outbreeding depression** | Reduction in fitness that occurs through the loss of local adaptation or co-adapted genes. A possible outcome of hybridization. |
| **Phenology** | The study of the seasonality of animal and plant life. |
| **Population** | A group of individuals of a single species in a particular area. |
| **Population bottleneck** | Reduction of a population to few individuals; may result in inbreeding depression. |
| **Scenario** | A hypothetical future world used to aid understanding of the potential impacts of climate change. |
| **Species richness** | The number of different species in a defined area at a particular time. |
| **Speciation** | The process of species formation. |
| **Synergy** | The interaction of two or more processes such that the total effect is greater than each process acting independently. |
| **Threshold** | A non-linearity in the response of a population or process to changing conditions. |
| **Vagile** | Endowed with freedom of movement. |
| **Weather** | The condition of the atmosphere over a short period of time, as described by various meteorological phenomena. |

# Appendix 2.

A summary of studies of climate change effects on vertebrate species that occur in Ontario. Effects on the studied population(s) are noted as expansion, contraction, or equivocal. Studies include peer-reviewed journal articles or books that quantitatively assessed long-term data (> 5 years) for population responses to changing climate. Some additional studies were included if they were of local Ontario interest. Vertebrate species that occur in Ontario not listed in the table have not had studies published concerning their responses to climate change. Of the 175 species listed in the table, 103 have reported effects that are equivocal, 62 have effects that are consistent with expansion, and 10 have effects consistent with contraction.

| Class | Common Name | Scientific Name | Documented effects of climate change on the population | Comment | Sources |
|---|---|---|---|---|---|
| Amphibia | American Toad | *Bufo americanus* | EQUIVOCAL | Spring call initiation unchanged 1900-1912 to 1990-1999 | Gibbs and Breisch 2001 |
| Amphibia | Bullfrog | *Rana catesbeiana* | EXPANSION | Spring call initiation earlier in 1990-1999 compared to 1900-1912 | Gibbs and Breisch 2001 |
| Amphibia | Fowler's Toad* | *Bufo fowleri* | EQUIVOCAL | Spring call initiation unchanged 1980 to 1998 | Blaustein et al. 2001 |
| Amphibia | Gray Treefrog | *Hyla versicolor* | EXPANSION | Spring call initiation earlier in 1990-1999 compared to 1900-1911 | Gibbs and Breisch 2001 |
| Amphibia | Green Frog | *Rana clamitans* | EQUIVOCAL | Spring call initiation unchanged 1900-1912 to 1990-1999 | Gibbs and Breisch 2001 |
| Amphibia | Red-backed Salamander | *Plethodon cinereus* | EQUIVOCAL | Leadback morph becoming more common, associated with warmer temperatures | Gibbs and Karraker 2005 |
| Amphibia | Spring Peeper | *Pseudacris crucifer* | EQUIVOCAL | Breeds earlier in warmer years | Blaustein et al. 2001, Gibbs and Breisch 2001 |
| Amphibia | Wood Frog | *Rana sylvatica* | EXPANSION | Spring call initiation earlier in 1990-1999 compared to 1900-1912 | Gibbs and Breisch 2001 |
| Reptilia | Painted Turtle | *Chrysemys picta* | CONTRACTION | Temperature-dependent sex determination; grow larger and reach maturity quicker during warmer sets of years | Janzen 1994, Frazer et al. 1993 |
| Aves | Alder Flycatcher | *Empidonax alnorum* | CONTRACTION | Spring arrival date became later 1899-1911 to 1994-1997 | Wilson et al. 2000 |

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|---|---|---|---|---|---|
| Aves | American Bittern | *Botaurus lentiginosus* | EQUIVOCAL | Spring arrival date in Maine unchanged 1899-1911 to 1994-1997; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | American Coot | *Fulica americana* | EXPANSION | Spring arrival is advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | American Kestrel | *Falco sparverius* | EQUIVOCAL | Spring arrival is unrelated to temperature in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | American Redstart | *Setophaga ruticilla* | EQUIVOCAL | Spring arrival is later in Maine; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | American Robin | *Turdus migratorius* | EQUIVOCAL | Spring arrival is earlier in parts of its range, not in others; lays eggs earlier in warmer springs; spring arrrival is advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Torti and Dunn 2005, Inouye et al. 2000, Wilson et al. 2000, Bradley et al. 1999 |
| Aves | American Woodcock | *Scolopax minor* | EXPANSION | Spring arrival is earlier in parts of its range; calling earlier | Butler 2003, Wilson et al. 2000, Bradley et al. 1999 |
| Aves | Bald Eagle | *Haliaeetus leucocephalus* | EXPANSION | Documented population increase | Ritchie and Ambrose 1996 |
| Aves | Baltimore Oriole | *Icterus galbula* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 in Maine; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | Bank Swallow | *Riparia riparia* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Barn Swallow | *Hirundo rustica* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later or unchanged in others; clutch size increase | Butler 2003, Moller 2002, Wilson et al. 2000 |
| Aves | Bay-breasted Warbler | *Dendroica castanea* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Belted Kingfisher | *Ceryle alcyon* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000, Bradley et al. 1999, |
| Aves | Black-and-white Warbler | *Mniotilta varia* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |

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|---|---|---|---|---|---|
| Aves | Black-billed Cuckoo | *Coccyzus erythropthalmus* | CONTRACTION | Spring arrival became later 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Blackburnian Warbler | *Dendroica fusca* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later in others | Butler 2003, Wilson et al. 2000 |
| Aves | Black-capped Chickadee | *Poecile atricapillus* | CONTRACTION | Hybridization with Carolina chickadees whose range is expanding | Curry 2005 |
| Aves | Black-crowned Night-Heron | *Nycticorax nycticorax* | EQUIVOCAL | Spring arrival in Manitoba is unrelated to temperature | Murphy-Klassen et al. 2005 |
| Aves | Blackpoll Warbler | *Dendroica striata* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Black-throated Blue Warbler | *Dendroica caerulescens* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Black-throated Green Warbler | *Dendroica virens* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Blue-headed Vireo | *Vireo solitarius* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Blue-winged Warbler | *Vermivora pinus* | EXPANSION | Spring arrival is earlier in some parts of its range; 85 km northward range expansion 1967-1971 to 1998-2002 | Hitch and Leberg 2006, Butler 2003 |
| Aves | Bobolink | *Dolichonyx oryzivorus* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later in others; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Broad-winged Hawk | *Buteo platypterus* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Brown Creeper | *Certhia familiaris* | EQUIVOCAL | Spring arrival is unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Brown Thrasher | *Toxostomum rufum* | EQUIVOCAL | Spring arrival is earlier in parts of its range, not in others; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000, Bradley et al. 1999 |
| Aves | Brown-headed Cowbird | *Molothrus ater* | EQUIVOCAL | Spring arrival is unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Canada Goose | *Branta canadensis* | EXPANSION | Onset of nesting earlier; spring arrival in Manitoba is advancing with warming temperatures | Murphy-Klassen et al. 2005, MacInnes et al. 1990 |
| Aves | Canada Warbler | *Wilsonia canadensis* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |

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|---|---|---|---|---|---|
| Aves | Cape May Warbler | *Dendroica tigrina* | | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Cardinal | *Cardinalis cardinalis* | EXPANSION | Calling earlier | Bradley et al. 1999 |
| Aves | Chestnut-sided Warbler | *Dendroica pensylvanica* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Chimney Swift | *Chaetura pelagica* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later in others | Butler 2003, Wilson et al. 2000 |
| Aves | Chipping Sparrow | *Spizella passerina* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Chuck-will's-widow | *Caprimulgus carolinensis* | EQUIVOCAL | No significant range shift 1967-1971 to 1998-2002 | Hitch and Leberg 2006 |
| Aves | Clay-coloured Sparrow | *Spizella pallida* | EQUIVOCAL | Spring arrival is unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Cliff Swallow | *Petrochelidon pyrrhonota* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Common Grackle | *Quiscalus quiscula* | EXPANSION | Spring arrival advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Common Loon | *Gavia immer* | EXPANSION | Spring arrival became earlier 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Common Nighthawk | *Chordeiles minor* | EQUIVOCAL | Spring arrival became later 1899-1911 to 1994-1997 in Maine; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | Common Snipe | *Gallinago gallinago* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, not in others; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Common Yellowthroat | *Geothlypis trichas* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 in Maine; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | Cooper's Hawk | *Accipiter cooperii* | EXPANSION | Spring arrival in Manitoba is unrelated to temperature | Murphy-Klassen et al. 2005 |
| Aves | Dark-eyed Junco | *Junco hyemalis* | EXPANSION | Spring arrival is advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Double-crested Cormorant | *Phalacrocorax auritus* | EXPANSION | Spring arrival in Manitoba is advancing with warming temperatures | Murphy-Klassen et al. 2005 |

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|---|---|---|---|---|---|
| Aves | Eastern Bluebird | *Sialia sialis* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later in Maine; lays eggs 4 days earlier than in the 1970s | Torti and Dunn 2005, Butler 2003, Wilson et al. 2000, Bradley et al. 1999 |
| Aves | Eastern Kingbird | *Tyrannus tyrannus* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 in Maine; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | Eastern Meadowlark | *Sturnella magna* | EXPANSION | Spring arrival is earlier in some parts of its range | Bradley et al. 1999 |
| Aves | Eastern Phoebe | *Sayornis phoebe* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later in others; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Bradley et al. 1999 |
| Aves | Eastern Wood-pewee | *Contopus virens* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Field Sparrow | *Spizella pusilla* | EQUIVOCAL | Spring arrival earlier in some parts of its range, later in others | Butler 2003, Wilson et al. 2000 |
| Aves | Fox Sparrow | *Passerella iliaca* | EQUIVOCAL | Spring arrival earlier in parts of its range, unchanged in others; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Golden-winged Warbler | *Vermivora chrysoptera* | EXPANSION | Spring arrival earlier in some parts of its range | Butler 2003 |
| Aves | Gray Catbird | *Dumetella carolinensis* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Gray Jay | *Perisoreus canadensis* | CONTRACTION | Populations decline following warmer autumns possibly due to hoard rot | Waite and Strickland 2006 |
| Aves | Gray-cheeked Thrush | *Catharus minimus* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Great Blue Heron | *Ardea herodias* | EXPANSION | Spring arrival is earlier in some parts of its range; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000, Bradley et al. 1999 |
| Aves | Great Crested Flycatcher | *Myiarchus crinitus* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Greater Yellowlegs | *Tringa melanoleuca* | EQUIVOCAL | Spring arrival is unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |

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|---|---|---|---|---|---|
| Aves | Green Heron | *Butorides virescens* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Henslow's Sparrow* | *Ammodramus henslowii* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Hermit Thrush | *Catharus guttatus* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later in others; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Hooded Warbler* | *Wilsonia citrina* | EXPANSION | 115 km range expansion 1967-1971 to 1998-2002 | Hitch and Leberg 2006 |
| Aves | Horned Grebe | *Podiceps auritus* | EXPANSION | Spring arrival is advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Horned Lark | *Eremophila alpestris* | EQUIVOCAL | Spring arrival is unrelated to temperature in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | House Wren | *Troglodytes aedon* | EQUIVOCAL | Spring arrival is earlier in some parts of its range; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Bradley et al. 1999 |
| Aves | Indigo Bunting | *Passerina cyanea* | EXPANSION | Spring arrival earlier in some parts of its range | Butler 2003, Wilson et al. 2000 |
| Aves | Killdeer | *Charadrius vociferus* | EXPANSION | Spring arrival is earlier in some parts of its range; lays earlier in warmer springs | Murphy-Klassen et al. 2005, Torti and Dunn 2005, Butler 2003 |
| Aves | Least Flycatcher | *Empidonax minimus* | EQUIVOCAL | Spring arrival date became later 1899-1911 to 1994-1997 in Maine; unrelated to advancing temperature in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | Least Sandpiper | *Calidris minutilla* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Lesser Yellowlegs | *Tringa flavipes* | EQUIVOCAL | Spring arrival is unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Lincoln's Sparrow | *Melospiza lincolnii* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Louisiana Waterthrush* | *Seiurus motacilla* | EQUIVOCAL | Spring arrival is earlier in parts of its range and later in others; No significant range shift 1967-1971 to 1998-2002 | Hitch and Leberg 2006, Butler 2003 |
| Aves | Magnolia Warbler | *Dendroica magnolia* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later in others | Butler 2003, Wilson et al. 2000 |
| Aves | Marsh Wren | *Cistothorus palustris* | EQUIVOCAL | Spring arrival is earlier in some parts of its range; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003 |

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|---|---|---|---|---|---|
| Aves | Mourning Dove | *Zenaida macroura* | EQUIVOCAL | Spring arrival is unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Mourning Warbler | *Oporornis philadelphia* | EQUIVOCAL | Spring arrival is earlier in parts of its range and later or unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Nashville Warbler | *Vermivora ruficapilla* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Northern Flicker | *Colaptes auratus* | EQUIVOCAL | Spring arrival became later 1899-1911 to 1994-1997 in Maine; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | Northern Harrier | *Circus cyaneus* | EXPANSION | Spring arrival in Manitoba is advancing with warming temperatures | Murphy-Klassen et al. 2005 |
| Aves | Northern Mockingbird | *Mimus polyglottus* | EQUIVOCAL | No significant range shift 1967-1971 to 1998-2002 | Hitch and Leberg 2006 |
| Aves | Northern Parula | *Parula americana* | EQUIVOCAL | Spring arrival is later in some parts of its range, not in others | Butler 2003, Wilson et al. 2000 |
| Aves | Northern Rough-winged Swallow | *Stelgidopteryx serripennis* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Northern Waterthrush | *Seiurus noveboracensis* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Olive-sided Flycatcher | *Contopus cooperi* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Osprey | *Pandion haliaetus* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Ovenbird | *Seiurus aurocapillus* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Palm Warbler | *Dendroica palmarum* | EQUIVOCAL | Spring arrival is later in some parts of its range; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003 |
| Aves | Pectoral Sandpiper | *Calidris melanotos* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Philadelphia Vireo | *Vireo philadelphicus* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Pied-billed Grebe | *Podilymbus podiceps* | EXPANSION | Spring arrival in Manitoba is advancing with warming temperatures | Murphy-Klassen et al. 2005 |
| Aves | Pine Warbler | *Dendroica pinus* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |

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|---|---|---|---|---|---|
| Aves | Prairie Warbler | *Dendroica discolor* | EQUIVOCAL | No significant range shift 1967-1971 to 1998-2002 | Hitch and Leberg 2006 |
| Aves | Purple Finch | *Carpodacus purpureus* | EXPANSION | Spring arrival advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Purple Martin | *Progne subis* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Red-eyed Vireo | *Vireo olivaceus* | EQUIVOCAL | Spring arrival earlier in parts of its range and later or unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Red-tailed Hawk | *Buteo jamaicensis* | EXPANSION | Spring arrival in Manitoba is unrelated to temperature | Murphy-Klassen et al. 2005 |
| Aves | Red-winged Blackbird | *Agelaius phoeniceus* | EXPANSION | Spring arrival is earlier in parts of its range; lays eggs 7.5 days earlier; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Torti and Dunn 2005, Wilson et al. 2000, Bradley et al. 1999 |
| Aves | Rose-breasted Grosbeak | *Pheuticus ludovicianus* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003, Wilson et al. 2000, Bradley et al. 1999 |
| Aves | Ruby-crowned Kinglet | *Regulus calendula* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Ruby-throated Hummingbird | *Archilochus colubris* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003, Wilson et al. 2000 |
| Aves | Rusty Blackbird* | *Euphagus carolinus* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Sandhill Crane | *Grus canadensis* | EQUIVOCAL | Spring arrival is unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Savannah Sparrow | *Passerculus sanwichensis* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, later in others | Butler 2003, Wilson et al. 2000 |
| Aves | Scarlet Tanager | *Piranga olivacea* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Semipalmated Sandpiper | *Calidris pusilla* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Sharp-shinned Hawk | *Accipiter striatus* | EQUIVOCAL | Spring arrival in Manitoba is unrelated to temperature | Murphy-Klassen et al. 2005 |

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| Aves | Short-eared Owl | *Asio flammeus* | EQUIVOCAL | Spring arrival is unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Snow Goose | *Chen caerulescens* | EQUIVOCAL | Onset of nesting earlier; spring arrival in Manitoba unrelated to temperature | Murphy-Klassen et al. 2005, MacInnes et al. 1990 |
| Aves | Solitary Sandpiper | *Tringa solitaria* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Song Sparrow | *Melospiza melodus* | EQUIVOCAL | Spring arrival became later 1899-1911 to 1994-1997 in Maine; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | Sora | *Porzana carolina* | EQUIVOCAL | Spring arrival is earlier in some parts of its range; unrelated to advancing temperature in Manitoba | Murphy-Klassen et al. 2005, Butler 2003 |
| Aves | Spotted Sandpiper | *Actitis macularia* | EXPANSION | Spring arrival is earlier in some parts of its range; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003 |
| Aves | Swamp sparrow | *Melospiza melodus* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Tennessee Warbler | *Vermivora peregrina* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003, Wilson et al. 2000 |
| Aves | Towhee | *Pipilio erythrophthalamus* | EQUIVOCAL | Did not show earlier arrival | Wilson et al. 2000, Bradley et al. 1999 |
| Aves | Tree Sparrow | *Spizella arborea* | EXPANSION | Spring arrival advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005 |
| Aves | Tree Swallow | *Tachycineta bicolor* | EQUIVOCAL | Spring arrival is earlier some parts of its range; Average egg-laying date up to 9 days earlier across NA; not laying earlier at Long Point, Ontario where temperatures have not increased; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Hussell 2003, Wilson et al. 2000, Dunn and Winkler 1999 |
| Aves | Turkey Vulture | *Cathartes aura* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Veery | *Catharus fuscescens* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Vesper Sparrow | *Pooecetes gramineus* | EQUIVOCAL | Spring arrival became later 1899-1911 to 1994-1997 in Maine; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Wilson et al. 2000 |
| Aves | Virginia Rail | *Rallus limicola* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Warbling Vireo | *Vireo gilvus* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Butler 2003, Wilson et al. 2000 |

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| Aves | Whip-poor-will | *Caprimulgus vociferus* | EXPANSION | Spring arrival is earlier in some parts of its range, later in others | Wilson et al. 2000, Bradley et al. 1999 |
| Aves | White-crowned Sparrow | *Zonotrichia leucophrys* | EQUIVOCAL | Spring arrival is earlier in some parts of its range; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003 |
| Aves | White-throated Sparrow | *Zonotrichia albicollis* | EQUIVOCAL | Spring arrival is earlier in some parts of its range; unrelated to warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Wilson's Warbler | *Wilsonia pusilla* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others; advancing with warming temperatures in Manitoba | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Winter Wren | *Troglodytes troglodytes* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Wood Duck | *Aix sponsa* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Wood Thrush | *Hylocichla mustelina* | EXPANSION | Spring arrival is earlier in some parts of its range | Bradley et al. 1999, Butler 2003 |
| Aves | Yellow Palm Warbler | *Dendroica palmarum hypochrysea* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Yellow Warbler | *Dendroica petechia* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Yellow-bellied Flycatcher | *Empidonax flaviventris* | EQUIVOCAL | Spring arrival date unchanged 1899-1911 to 1994-1997 | Wilson et al. 2000 |
| Aves | Yellow-bellied Sapsucker | *Sphyrapicus varius* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Butler 2003, Wilson et al. 2000 |
| Aves | Yellow-billed Cuckoo | *Coccyzus americanus* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |
| Aves | Yellow-breasted Chat | *Icteria virens* | EQUIVOCAL | No significant range shift 1967-1971 to 1998-2002 | Hitch and Leberg 2006 |
| Aves | Yellow-rumped Warbler | *Dendroica coronata* | EQUIVOCAL | Spring arrival is earlier in some parts of its range, unchanged in others | Murphy-Klassen et al. 2005, Butler 2003, Wilson et al. 2000 |
| Aves | Yellow-throated Vireo | *Vireo flavifrons* | EXPANSION | Spring arrival is earlier in some parts of its range | Butler 2003 |

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| Mammalia | Arctic Fox | *Alopex lagopus* | CONTRACTION | Competition and predation by red foxes expanding north | Selås and Vik 2006, Hersteinsson and Macdonald 1992 |
| Mammalia | Caribou* | *Rangifer tarandus* | CONTRACTION | Reduced body weight of calves | Weladji and Holand 2003 |
| Mammalia | Deer Mouse | *Peromyscus maniculatus* | EQUIVOCAL | No effect of climate on initiation of spring breeding 1985 to 2003 | Millar and Herdman 2004 |
| Mammalia | Elk | *Cervus elaphus* | EQUIVOCAL | Phenotypic plasticity in calving date during a 30 year study | Nussey et al. 2005 |
| Mammalia | Fisher | *Martes pennanti* | EXPANSION | Documented range expansion, related to snow depth | Carr et al. 2007a,b, Voigt et al. 2000 |
| Mammalia | Gray Wolf | *Canis lupus* | EQUIVOCAL | Increased pack size in years with deeper snow | Post et al.1999 |
| Mammalia | Least Weasel | *Mustela nivalis* | EXPANSION | Documented range expansion into Great Plains | Frey 1992 |
| Mammalia | Little Brown Bat | *Myotis lucifugus* | EXPANSION | Energetic limit for hibernation shifting north | Humphries et al. 2002 |
| Mammalia | Lynx | *Lynx canadensis* | EQUIVOCAL | Lynx-hare cycle related to climate | Stenseth et al. 1999 |
| Mammalia | Marten | *Martes americana* | EQUIVOCAL | Possible contraction in response to expanding fishers | Krohn et al. 1995, 1997 |
| Mammalia | Masked Shrew | *Sorex cinereus* | EXPANSION | Increased body size since 1950; documented range expansion into Great Plains | Yom-Tov and Yom-Tov 2005, Frey 1992 |
| Mammalia | Meadow Jumping Mouse | *Zapus hudsonius* | EXPANSION | Documented range expansion into Great Plains | Frey 1992 |
| Mammalia | Meadow Vole | *Microtus pennsylvanicus* | EXPANSION | Documented range expansion into Great Plains | Frey 1992 |
| Mammalia | Mink | *Neovison vison* | EQUIVOCAL | Mink-muskrat cycle related to climate | Haydon et al. 2001 |
| Mammalia | Moose | *Alces alces* | CONTRACTION | Increased disease at southern range boundary; cumulative effects of weather on body condition | Murray et al. 2006, Post and Stenseth 1998 |
| Mammalia | Muskrat | *Ondatra zibethicus* | EQUIVOCAL | Mink-muskrat cycle related to climate | Haydon et al. 2001 |
| Mammalia | Northern Flying Squirrel | *Glaucomys sabrinus* | CONTRACTION | Range contracts in response to competition from expanding southern flying squirrel populations | Bowman et al. 2005, Weigl 1978 |
| Mammalia | Opossum | *Didelphis virginiana* | EXPANSION | Documented range expansion | Kanda 2005, Austad 1988 |
| Mammalia | Polar Bear* | *Ursus maritimus* | CONTRACTION | Decreasing body condition and productivity | Obbard et al. 2006, Derocher et al. 2004, Stirling et al. 2004 |
| Mammalia | Porcupine | *Erethizon dorsatum* | EXPANSION | Porcupines following warming associated poleward shift in tree line; expansion related to reduced winter severity | Voigt et al. 2000, Payette 1987 |

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| Mammalia | Raccoon | *Procyon lotor* | EXPANSION | Documented range expansion; related to reduced winter severity | Larivière 2004, Voigt et al. 2000 |
| Mammalia | Red Fox | *Vulpes vulpes* | EXPANSION | Expanding north due to temperatures | Selås and Vik 2006, Hersteinsson and Macdonald 1992 |
| Mammalia | Red Squirrel | *Tamiasciurus hudsonicus* | EXPANSION | Onset of breeding advanced by 18 days over a 10-year study | Réale et al. 2003 |
| Mammalia | Snowshoe Hare | *Lepus americanus* | EQUIVOCAL | Lynx-hare cycle related to climate | Stenseth et al. 1999 |
| Mammalia | Southern Flying Squirrel | *Glaucomys volans* | EXPANSION | Energetic bottleneck shifting north, but dynamic boundary | Bowman et al. 2005, Weigl 1978 |
| Mammalia | White-tailed Deer | *Odocoileus virginianus* | EXPANSION | Cumulative effects of snow depth reduce body condition and fecundity; winter severity causes range contraction | Garroway and Broders 2005, Patterson and Power 2002, Voigt et al. 2000, Post and Stenseth 1999 |

* Species-at-risk

## Climate Change Research Publication Series

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CCRR-01 Wotton, M., K. Logan and R. McAlpine. 2005. Climate Change and the Future Fire Environment in Ontario: Fire Occurrence and Fire Management Impacts in Ontario Under a Changing Climate. Ontario Ministry of Natural Resources, Applied Research and Development Branch, Sault Ste. Marie, Ontario. Climate Change Research Report CCRR-01. 23 p.

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(0.3k P.R. 07 09 15)
ISBN 978-1-4249-4947-2 (print)
ISBN 978-1-4249-4948-9 (PDF)